OTEC ENVIRONMENTAL STUDIES OFFSHORE KAHE POINT, OAHU

Coastal Zone Manag

Department of Planning and Economic Development

OTEC ENVIRONMENTAL STUDIES
OFFSHORE KAHE POINT, OAHU

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SECTION 1

INTRODUCTION

In 1979 and early 1980, the State, through the Ad Hoc Committee on the Advancement of OTEC for Hawaii, prepared and produced OTEC for Oahu, a report on the Development of a Pilot Plant for Ocean Thermal Energy Conversion (OTEC) at Kahe Point, Oahu, Hawaii. That report provides the framework for this report and describes the Hawaiian setting for OTEC and the rationale for selecting Kahe Point as the optimal site for an OTEC plant. The report also identifies the environmental studies that had been performed through early 1980 and those that would be required for facility design and environmental impact assessment purposes.

In brief, the Kahe Point area was selected as the optimal site off Oahu in as much as (1) The Hawaiian Electric Company (HECO) Kahe Generating Station provides an optimum point of interconnection between an offshore OTEC facility and the island's electrical distribution system; (2) the marine environmental characteristics of the Kahe Point area are favorable to the siting of an offshore OTEC facility; (3) electrical transmission cables interconnecting the OTEC facility and the generating station can be brought ashore through existing outfall discharge pipes, thereby negating the need to further disturb the ecologically sensitive shoreline-surfzone area; (4) the site is close to the center of Honolulu and the infrastructural components, such as Honolulu International Airport, Honolulu Harbor, the University of Hawaii, computing and communications centers, office space, and other support services, that will be required; (5) environmental impacts (i.e., extensive buildings, pavement or other disruptions) will not be significant on the island of Oahu, thereby negating the need to change the existing land characteristics of the Kahe Point area; and (6) an offshore OTEC facility will add to the fishery resources of the area by acting as a fish aggregating device, thereby aiding both commercial and recreational fishermen.

The OTEC for Oahu report identified several environmental areas that required further study. The present study was performed to fulfill three of the noted additional study requirements. First, a comprehensive review of pertinent literature has been performed. During the performance of this work, over 175 scientific, technical and popular literature sources specifically concerned with the Kahe Point area, as well as with OTEC in general in Hawaii were reviewed. A complete list of the physical, chemical and biological oceanographic literature reviewed is provided in Section 5 (Conclusions) of this report.

Second, the present study includes a literature review and field investigations of the recreational and commercial fishing use of the area offshore of Kahe Point. The fisheries literature reviewed is also listed in Section 5. Field investigations included interviewing sport fishermen and fishing clubs to determine the amount of recreational fishing occurring in the area and to record the species, sizes and numbers of fish caught in the Kahe OTEC facility area. This portion of the present study provides an indication of the species of adult pelagic fish taken from the Kahe Point area, for both recreational and commercial purposes.

Third, as recommended in the OTEC for Oahu report, a larval pelagic fish survey was performed. This work provides an indication of the ecological value of the Kahe Point area as a fish nursery area and the possible effects of an OTEC facility on the entrapment, impingement and entrainment of larval and juvenile fish. The data collected during this part of the study is provided in Appendix B.

Fourth, although not specifically noted as an environmental area requiring additional study, a brief investigation of the visual impacts of an offshore OTEC facility was conducted. It was determined through discussions with members of the Ad Hoc OTEC Committee and other interested and involved individuals, that since the offshore vista may be altered by the presence of an OTEC facility, an initial investigation into the potential visual impacts should be conducted. Appendix C contains the results of the visual impact study performed for this report.

The following sections of this report describe the surveys and investigations performed and present the results of that work. Potential impacts, both positive and negative, also are discussed. Finally, recommendations for future work areas are presented. The bulk of this report has been prepared using nontechnical or simplified technical terms. However, Appendices A and B are the technical source reports upon which the oceanographic parameters discussed in this report have been based and are provided to assist those interested and conversant in the technical terminology.

For the purposes of this report, it was determined that the Kahe OTEC study area would be defined as the area between Barbers Point and Pokai Bay and extending to a distance five miles offshore (see Figure 1). The 3,280-foot contour occurs roughly at this five-mile boundary. Therefore, data, information and studies collected within this potential OTEC area are considered site specific, and those outside the area have been termed "Hawaiian" (see Appendix A, Part 2). Since the Hawaiian offshore oceanographic realm is relatively similar physically, biologically and chemically, these "Hawaiian" studies are still of use in establishing general baseline environmental conditions.

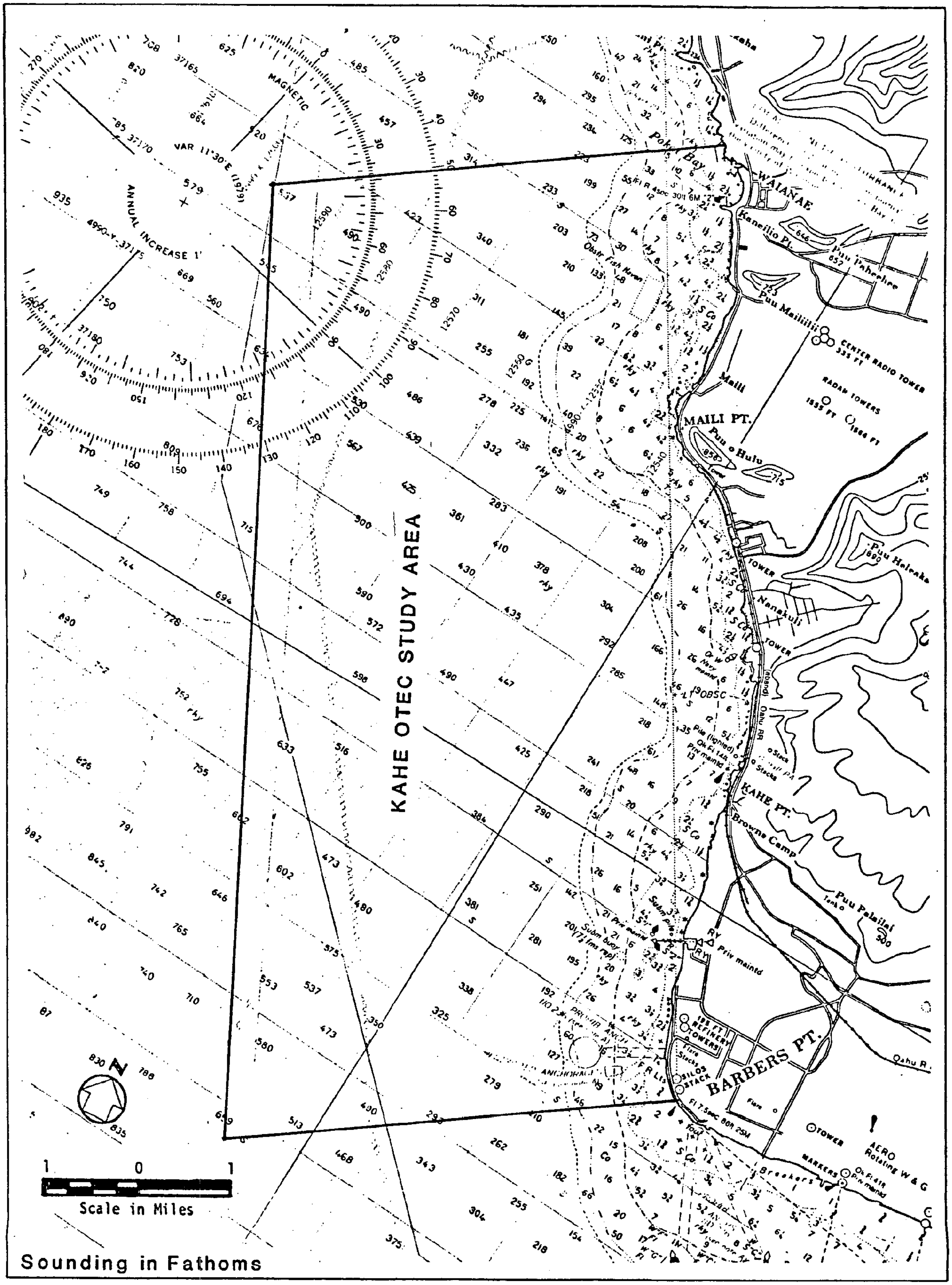


FIGURE 1. KAHE OTEC STUDY AREA

SECTION 2

LITERATURE REVIEW OF THE PHYSICAL, CHEMICAL AND BIOLOGICAL OCEANOGRAPHIC DATA PERTINENT TO THE KAHE POINT OTEC SITE

INTRODUCTION

A tedious, but nonetheless necessary task of any credible technical investigation is a thorough review of existing literature. This task involves searching not only technical publications but also popularly written articles. During the course of the present work, approximately 175 published articles were located, and are cited, that pertain directly and indirectly to the marine biological, chemical, physical oceanographic, fishery or visual impacts of an OTEC facility being established offshore Kahe Point. The majority of the technical literature regarding the Kahe Point area has been prepared in relation to the Hawaiian Electric Company (HECO) Kahe Point Generating Station and is concerned primarily with the near-shore environment, that is, within one mile of the shoreline. A larger body of information has been developed for areas outside the Kahe OTEC study area.

The principle source of offshore site specific chemical, biological and physical oceanographic information on the Kahe OTEC study area is that collected during the recently completed Oahu OTEC Environmental Benchmark Survey (Noda, et al, 1981). This baseline environmental study consisted of a series of oceanographic cruises over a one year period from May 1980 to May 1981.

As previously noted, other site specific studies have, for the most part, concentrated on the area around the Kahe Generating Station; have been concerned with the biological conditions of the area; and have been confined to an area extending one mile or less offshore.

These studies (see Leis, 1978; Leis and Miller, 1976; Miller, 1974 and 1978; Environmental Consultants, 1974; Ziemann, 1977; and AECOS, Inc., 1980) have investigated the effects of entrainment through the Kahe Generating Station on resident zooplankton communities, provided data on the taxonomic composition, relative abundance and mortality rates and described in detail the biological and physical characteristics of the nearshore area and uses of the area for commercial or recreational purposes. Additionally, as part of an on-going data collection effort associated with the development of a statewide system of fish aggregation devices (or FAD's) by the Hawaii Division of Fish and Game, in conjunction with the University of Hawaii Sea Grant Program, the State Marine Affairs Coordinator and the National Marine Fisheries Service records are being kept of commercial and recreational fishing activities within the Kahe OTEC study area.

Physical Oceanographic Characteristics and Offshore Physiography

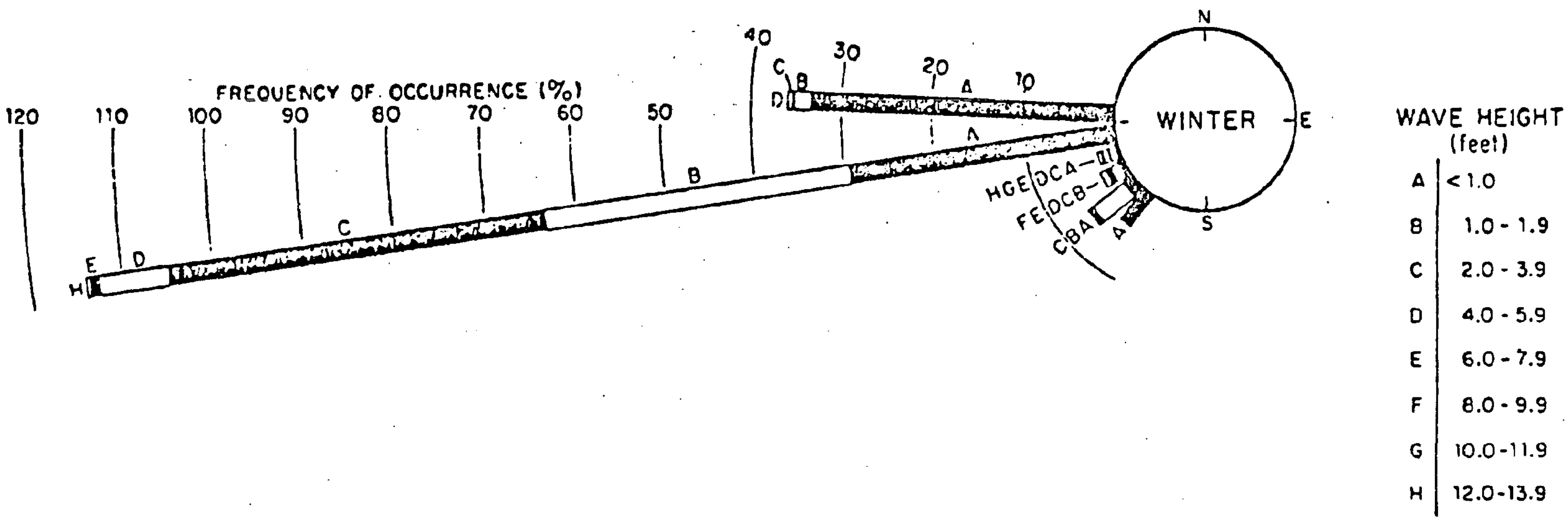
Kahe Point is approximately 20 miles west of Honolulu Harbor, the principal National Oceanographic and Atmospheric Administration (NOAA) tidal gauge station. Water elevation measurements taken by HECO at the intake structure of the Kahe Generating Station indicate that Honolulu Harbor daily tidal predictions are adequate for the Kahe area. Similarly, the U.S. Navy, Fleet Weather Central, Pearl Harbor, Oceanographic Outlook, Waianae Coast of Oahu, indicates that the tidal elevation predictions for Honolulu Harbor are approximately 15 minutes ahead of the same tidal elevation for the Kahe Point area. Table 1 provides tidal data for the Kahe area.

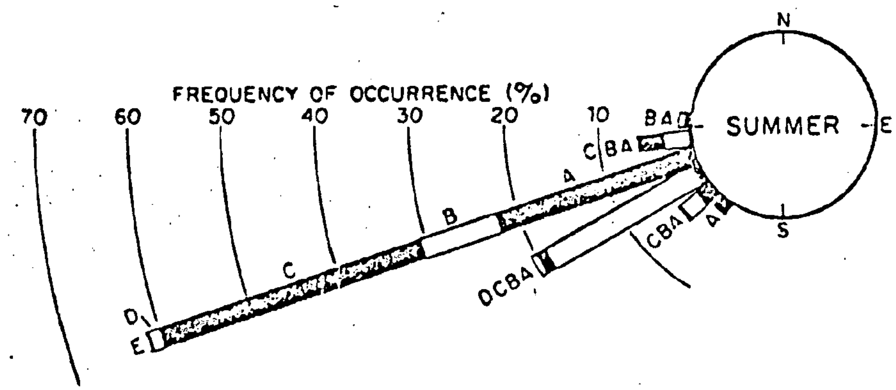
The wave climate characteristics off the Kahe Point area have been described by Marine Advisors (1964) and those off Barbers Point by Conoco-Dillingham (1972). In general, waves from the west and west-southwest prevail during the winter months. This is also the period of greatest wave heights as shown in Figure 2. During the

TABLE 1

TIDAL DATA FOR THE KAHE POINT AREA

Location	Position		Difference				Ranges		Mean Level
	Lat.	Long.	Time		Height				
	0'	0'	H.W.	L.W.	H.W.	L.W.	Mean	Diurnal	
	North	West	h.m.		Feet		Feet		Feet
Honolulu	21-18	157-52	Daily Predictions				1.2	1.9	0.8
Waianae	21-27	158-12	+0 18	+0 15	0.0	0.0	1.2	1.8	0.8
Kahe (interpolation)	21-22	158-08	+0 12	+0 10	0.0	0.0	1.2	1.8	0.8
Kahe (observations)			-0 30		+0.2	---		2.0	
Kahe (suggested)			0 00	0 00	+0.1	0.0	1.2	1.9	0.8





Note: There is no fixed correspondence between the black-white scheme and the wave height groups. Each ray begins with black at the central circle, regardless of whether the initial height group is A, B, C, etc.; thereafter black and white alternate continously along the ray regardless of whether all height groups are present or not. Letters along, or at the end of, the ray indicate the sequence of height groups present in that ray.

Source: Marine Advisors, 1964

FIGURE 2. BREAKING WAVE ROSES AT KAHE FOR TYPICAL YEAR

summer, wave direction is from the southwest to south-southwest sector and wave heights diminish. The predominant wave directions are responsible for longshore transport toward the north in summer and toward the south in winter.

Summer breaker heights due to tradewind generated waves are generally small. Breaker heights of other wave types ("Kona" or southerly storm and North Pacific swell) are reduced at the shoreline since Maili Point and Barbers Point (see Figure 1) act as wave barriers. Offshore, however, breakers may reach heights of six feet during storm wave conditions.

The directions and characteristics of currents in the potential Kahe OTEC area have been summarized by Bathen (1978). In general, currents can be highly variable depending on the specific location or season. Currents are generally weak along the leeward coast of Oahu, except near Barbers Point and Kaena Point. Current variations are particularly evident at specific locations where the influence of bottom topography, eddies and longshore currents become significant. For example, off Barbers Point current velocities up to 0.8 knots have been measured and greater velocities have been reported. From approximately 500 feet offshore of Kahe, water circulation depends primarily on tidal-induced currents and wave-driven ocean currents. The tidal-induced current component is fairly consistently southward on flood tide and northerly on ebb tide cycles.

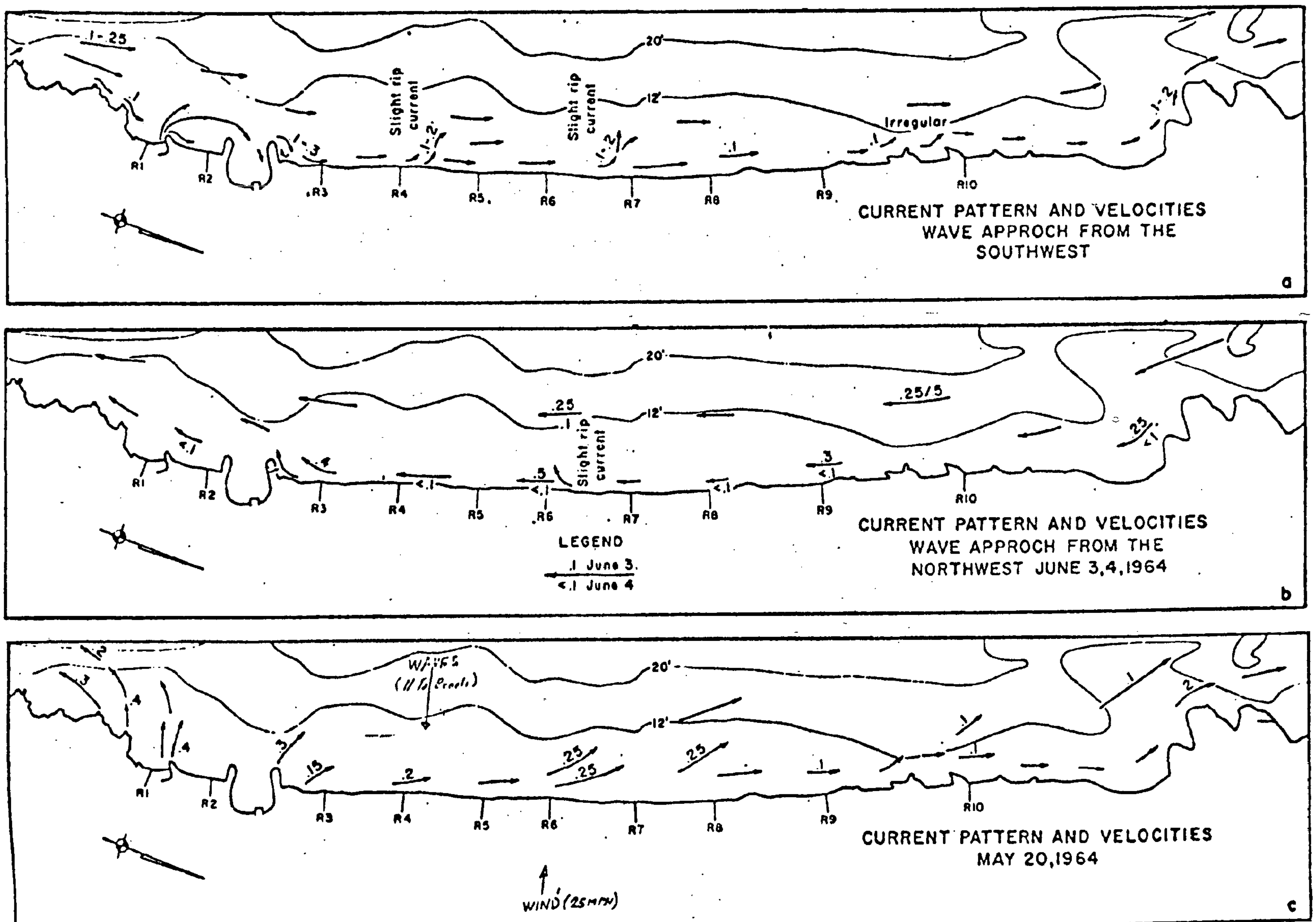
In contrast to this offshore current pattern, Leis (1978) found the opposite pattern for tidal currents within 500 feet of the shoreline. Currents on ebb tides set toward the south and southwest and reverse during flood tides. Inshore current velocities are greater than offshore and reach a maximum during summer months (median equal to 1.9 knots). The opposing patterns of tidally induced currents for offshore and nearshore areas indicate an eddy system of flow reversal off Kahe (Leis, 1978).

The effects of wind and wave action on currents are superimposed over the tidal effects. Although a shallow layer of surface water generally moves in the direction of the wind, the mass transport of water is in the direction of propogation by waves and also causes surface water motion. Marine Advisors (1964) found that in the absence of strong winds, currents generally tend to flow parallel to the bottom contours.

Littoral zone currents in the Kahe area are basically related to wave action and wave approach to shore. The intermediate area between the littoral and deep zones can be affected by either tides or waves. During times when tidal changes are extreme and waves are slight, water movement in the intermediate zone is affected primarily by deep water currents. However, when the tidal effects are small, the intermediate zone water movements are dominated by the wave regime. Figure 3 represents current patterns and velocities observed under different tidal conditions with the wave approach from different quadrants. As shown, different current directions and velocities occur with different wind and wave conditions. Detailed tidal, wave and current information is provided in Appendix B and in Noda, et al (1981).

The Oahu OTEC Environmental Benchmark Survey (Noda, et al, 1981) provides biological, chemical and physical oceanographic data and is as complete a baseline environmental study as possible within the time and budgetary constraints imposed on the survey. During the year-long Kahe OTEC Environmental Benchmark Survey, water samples from 13 depths between the surface and approximately 3,280 feet were collected on each of three hydrocasts at each of two stations, one off Kahe Point and one off Maili Point (Figure 4).

Water from these samples was analyzed for dissolved nutrients (nitrate-nitrite, ammonium, phosphate and silicate), total nitrogen, phosphorous and carbon, dissolved oxygen, salinity, pH and



Source: Marine Advisors, 1964

FIGURE 3. CURRENT PATTERNS AND VELOCITY IN THE KAHE AREA

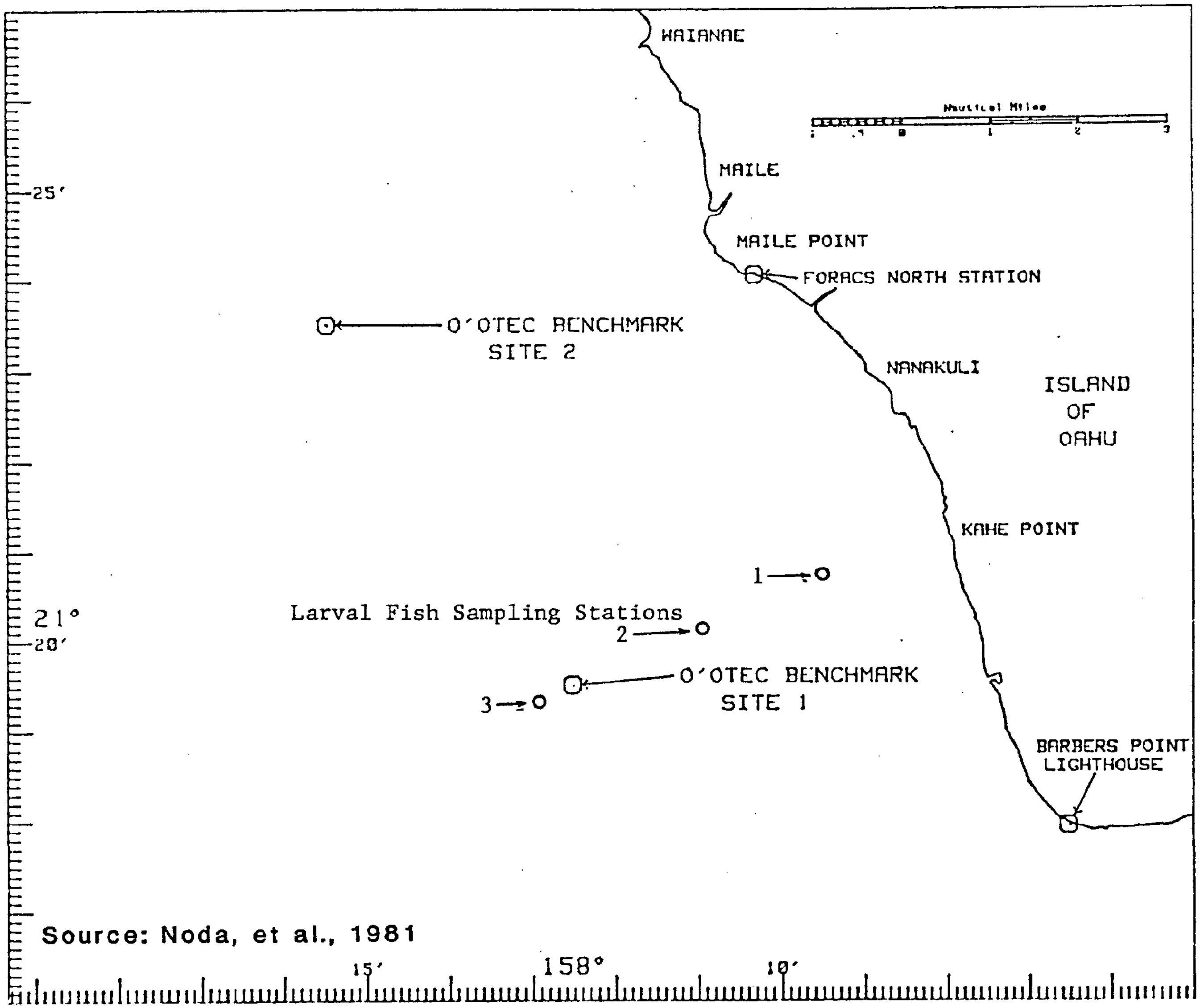


FIGURE 4. LOCATION OF LARVAL FISH SAMPLING STATIONS AND O'OTEC BENCHMARK SITE LOCATIONS

alkalinity. Water samples from the upper 500 feet were also analyzed for primary productivity, plant pigment concentrations and levels of adenosine triphosphate (ATP).

In addition to the water sampling program, net tows for zooplankton and larval fish were taken at both sampling stations. Surface tows were made with a surface sampling neuston net, while subsurface oblique tows, covering four depth intervals, were taken using an opening-closing plankton net. The zooplankton samples collected were analyzed for species composition and abundance and biomass (dry weight, ash-free dry weight, carbon and nitrogen).

As noted in the introductory section of this report, larval fish and plankton collections were made for the purposes of this study. The results of these collection efforts are contained in Appendix B. Other, primarily biological, surveys of the Kahe OTEC study area have included those conducted as part of HECO's National Pollutant Discharge Elimination System (NPDES) monitoring program. These studies and results therefrom are described in Leis (1978), Leis and Miller (1976), Miller (1974 and 1978), Environmental Consultants (1974) and Ziemann (1977). Additionally, McCain and Peck (1972), Coles and McCain (1973), Coles and Fukuda (1975), McCain (1977), Coles (1980) and Coles, Fukuda and Lewis (1981) have described the effects of the Kahe Generating Station on the nearshore biota.

For areas outside the immediate Kahe OTEC study area, the work most able to afford directly comparable data to the above noted Noda, et al (1981) OTEC Benchmark Environmental Survey, is the OTEC Benchmark Environmental Study conducted by AECOS (1979) and Noda, et al (1980) off the island of Hawaii (Big Island) during the October 1978 to December 1979 period. This work was conducted at the then proposed OTEC-1 test platform location, approximately 18 miles seaward of Kawaihae Harbor. The surveys included water sampling for chemical and biological analyses purposes, as well as current measurements. Additionally, there have been numerous studies on the ecology of various groups of Hawaiian marine vertebrates and invertebrates. For example, see Clarke (1973, 1974 and 1978) for information on myctophid, stomiatoid, and other families of fishes. Crustaceans have been studied by Walters (1976), Hu (1978), Riggs (1977) and Ziemann (1975). Micronektonic fishes have been studied by Amesbury (1975), Clarke and Wagner (1976) and the entire micronektonic community off Oahu by Maynard, et al (1975). A complete list of the physical, chemical and biological oceanographic literature reviewed for the purposes of this report appears at the end of Section 5.

SECTION 3

RECREATIONAL AND COMMERCIAL FISHING SURVEY AND LITERATURE REVIEW

In order to assess the value of the Kahe OTEC study area for fishing activities, field surveys of recreational fishermen and interviews with fishing club members were conducted. Additionally, the available literature was searched for data on historical fishing activities and National Marine Fisheries Service (NMFS) and State Division of Fish and Game (F&G) fish catch data were reviewed. The literature reviewed is listed at the conclusion of Section 5.

The results of the literature reviewed indicate that the area bounded by Barbers Point and Pokai Bay and extending five miles offshore is a relatively heavily fished area. Both recreational and commercial fishermen operate in the area, as do aquarium fish collectors. The types of fishing gear used range from traditional handline and pole and line methods to inshore netting, spearing, commercial trapping for Kona crabs and commercial netting offshore. It is estimated that at least 4,000 of Oahu's resident population of fishermen frequent the inshore areas of the Kahe OTEC region. Recreationally, the Barbers Point Barge Harbor is heavily fished, as is the coastal area north of Kahe Beach Park. The distribution of recreational and commercial fishing activities is shown in generalized form in Figure 5.

A. Commercial Fishing Activity

As described in Part 3 of Appendix A, the area between Maili Point and Barbers Point and extending offshore to a distance of 20 miles produces average annual commercial fish landings of between 50,000 and 75,000 pounds, excluding skipjack tuna. The skipjack tuna catch within this area averages between 250,000 and 500,000

KEY TO FISHING USES

A. NETTING
1. Lay netting
2. Crabbing
3. Throw netting
4. Bait collecting
5. Aquarium fish collecting

B. HOOK AND LINE
1. Shorecasting
2. Hand pole and line
3. Bottom handlining
4. Trolling

C. SPEARING
1. Diving
2. Torchfishing
3. Squidding

D. TRAPPING

E. GATHERING
1. 'Opihi
2. Limu
3. Wana
4. Lobster
5. Shell collecting
6. Miscellaneous (coral heads, other)

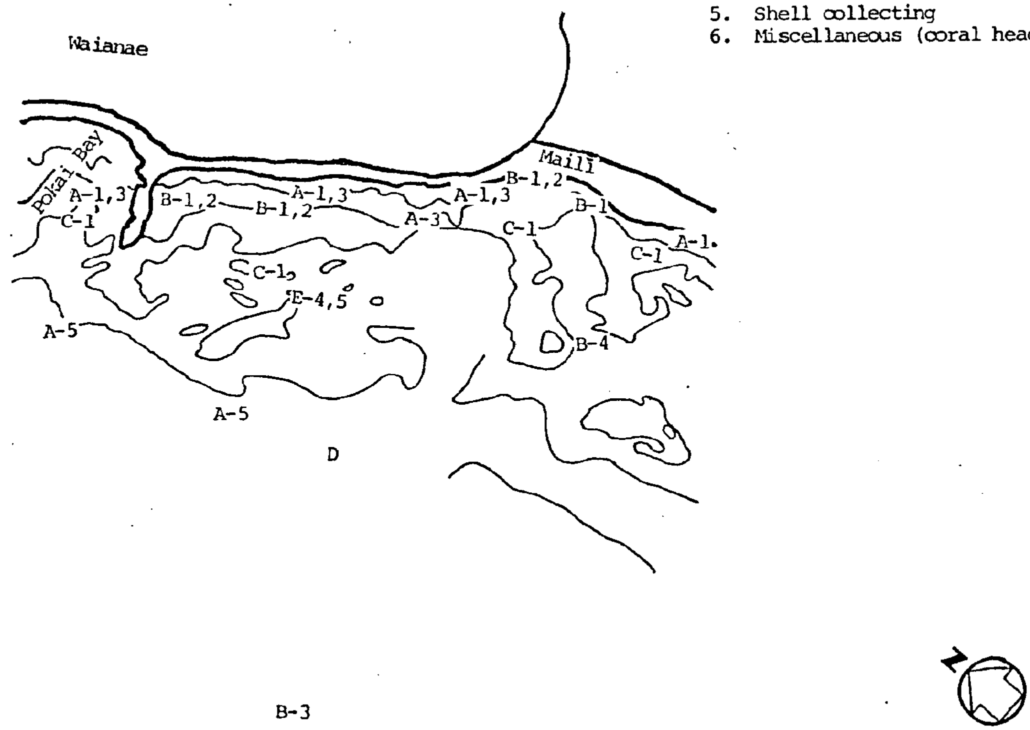


FIGURE 5. DISTRIBUTION OF RECREATIONAL AND COMMERCIAL FISHING USES IN THE KAHE OTEC REGION

KEY TO FISHING USES

A. NETTING
1. Lay netting
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1. Diving
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D. TRAPPING

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2. Limu
3. Wana
4. Lobster
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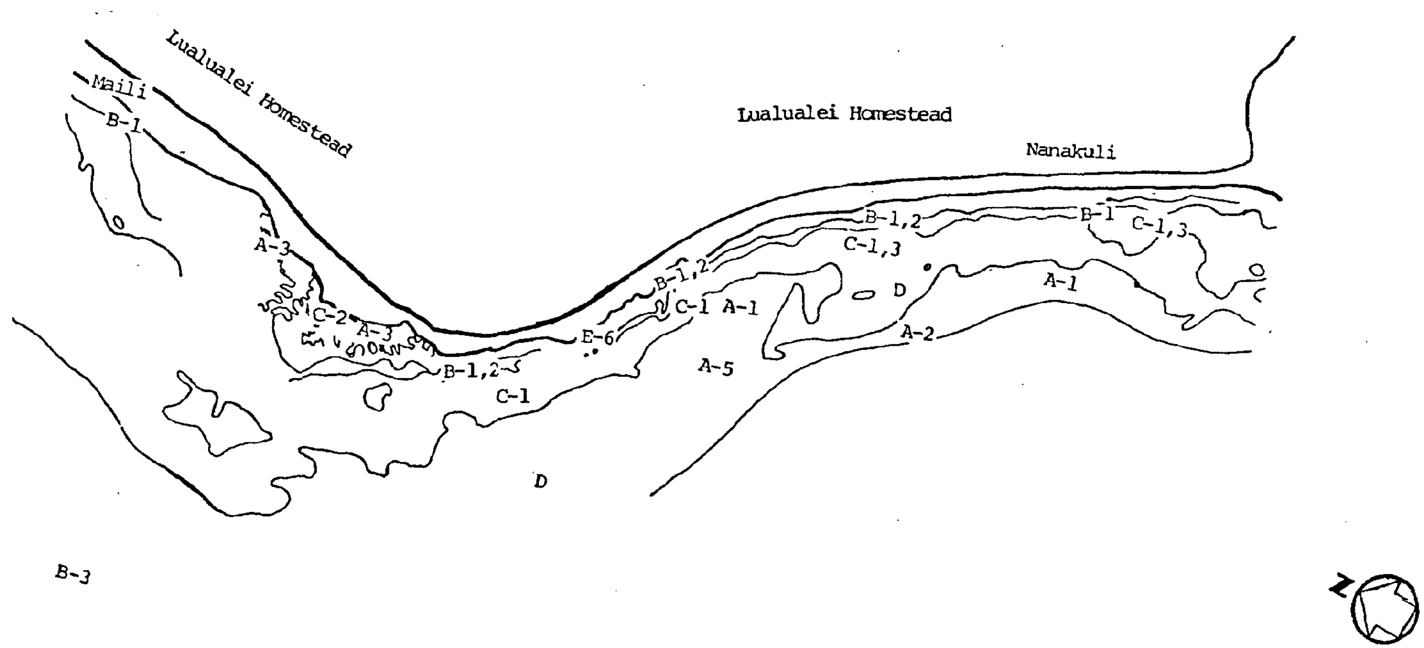

FIGURE 5. DISTRIBUTION OF RECREATIONAL AND COMMERCIAL FISHING USES IN THE KAHE OTEC REGION (CONTINUED)

KEY TO FISHING USES

A. NETTING
1. Lay netting
2. Crabbing
3. Throw netting
4. Bait collecting
5. Aquarium fish collecting

B. HOOK AND LINE
1. Shorecasting
2. Hand pole and line
3. Bottom handlining
4. Trolling

C. SPEARING
1. Diving
2. Torchfishing
3. Squidding

D. TRAPPING

E. GATHERING
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2. Limu
3. Wana
4. Lobster
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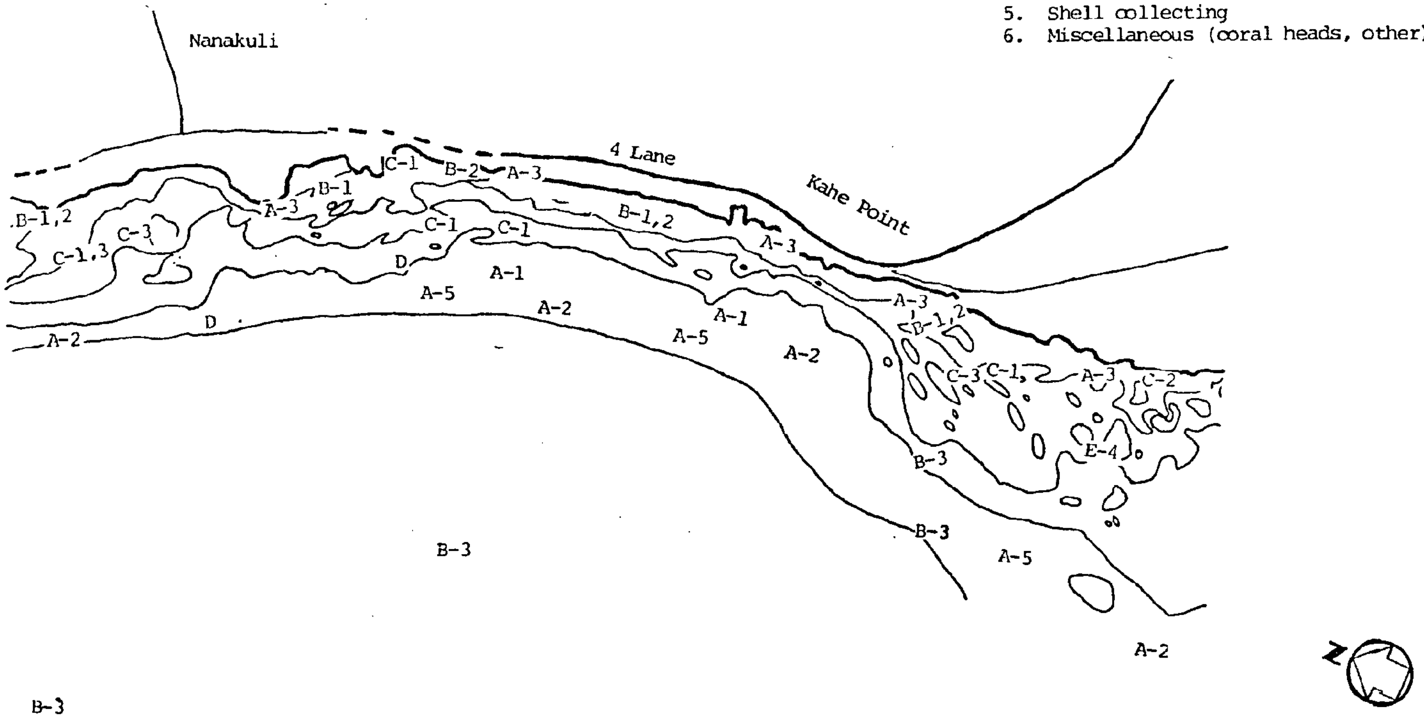

FIGURE 5. DISTRIBUTION OF RECREATIONAL AND COMMERCIAL FISHING USES IN THE KAHE OTEC REGION (CONTINUED)

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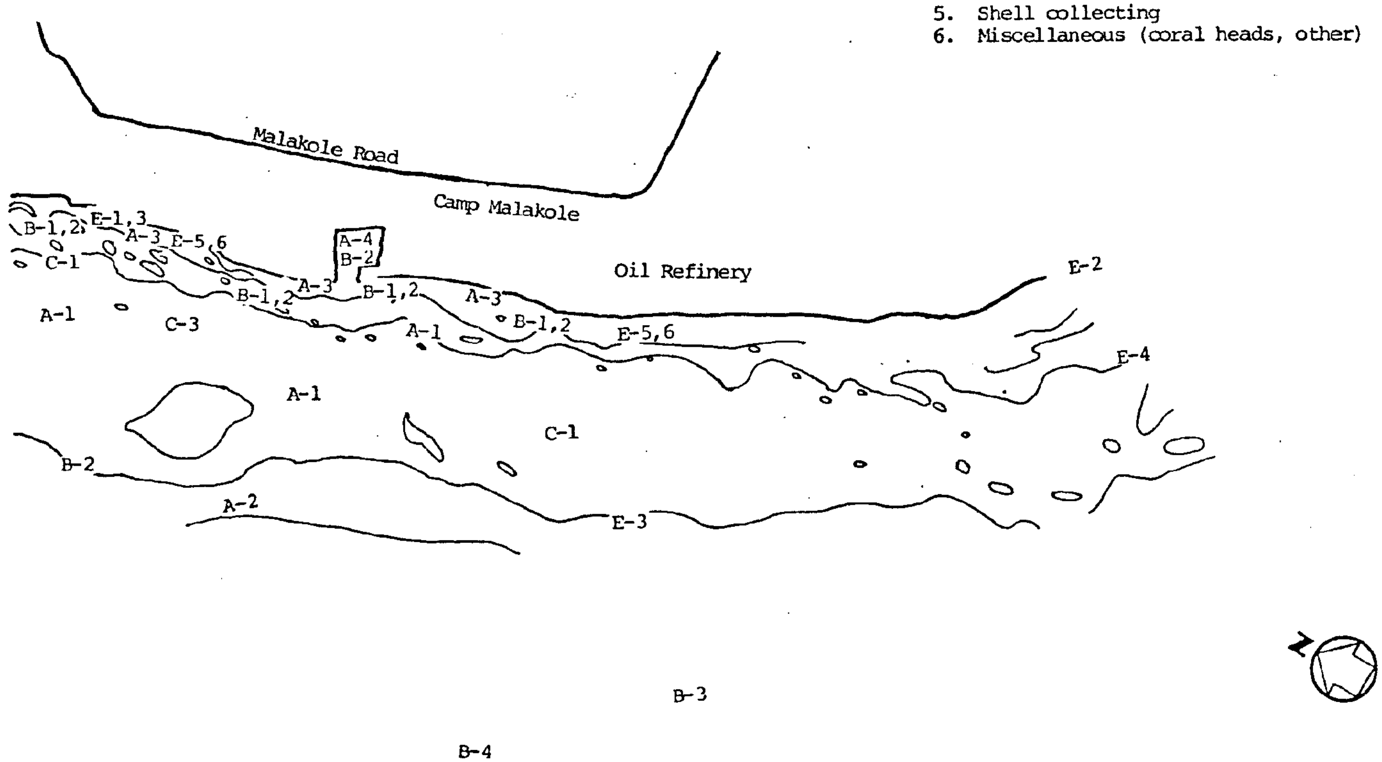

FIGURE 5. DISTRIBUTION OF RECREATIONAL AND COMMERCIAL FISHING USES IN THE KAHE OTEC REGION (CONTINUED)

pounds per year. Off Kahe, trapping of Kona crabs is a significant commercial fishery over sand bottoms at depths between 50 and 300 feet. Table 2 lists the common fishes of high commercial value found in the Kahe OTEC region. Table 3 indicates the average seasonal catch of major commercially valuable marine life in the Kahe OTEC region. As shown in Table 3 skipjack and yellowfish tuna account for the largest catches per season. However, as noted above, it is likely that a majority of the catch is taken outside the immediate Kahe OTEC region. Also, it has been indicated by appropriate data collection agencies that there is a tendency by fishermen to under-report their catches.

B. Recreational Fishing Activity

In addition to commercial trolling, recreational trolling is also conducted offshore, primarily on weekends by vessels ranging from 14 to 35 feet. This activity combines recreational fishing with subsistence and commercial fishing. Catch per unit effort is variable and the area trolled usually includes the Kahe OTEC region as well as the rest of leeward Oahu. The primary target species are yellowfin tuna and blue marlin. Other various billfish and tuna species are also taken.

In general, recreational trolling is concentrated between Kahe Point and Maili Point. On summer weekends, when ocean conditions are favorable, it is common for 50 to 100 recreational trollers to be fishing in the northern portion of the Kahe OTEC region. It is estimated that over a given period of time, at least 300 sportfishing vessels fish in the Kahe OTEC region. Overall, the shoreline and inshore areas north of Pokai Bay (outside the OTEC study area) provide more successful fishing than the specific study area. This is reflected in terms of catch per hour, numbers of recreational fishermen and recreational fish catches.

TABLE 2

RELATIVELY COMMON FISHES OF HIGH COMMERCIAL VALUE
FOUND IN THE KAHE OTEC REGION

Family	Scientific Name	Local Name	General Habitat	Usual Methods Of Capture
Squirrelfishes	*Myripristis* sp.	'u'u (menpachi)	Surge Zone Sub-Surge Zone	Spear Hook and Line Trap
Mugilidae	*Neomyxus chaptalii*	uouoa	Surge Zone	Throw Net
Kuhliidae	*Kuhlia sandvicensis*	aholehole	Surge Zone	Throw Net Hook and Line Spear
Priacanthidae	*Priacanthus cruenatus*	aweoweo	Surge Zone	Hook and Line Spear
Jacks	*Caranx* sp.	papio	Surge Zone Sub-Surge Zone	Hook and Line
	Decapterus macarellus	'opelu	Sub-Surge Zone	Hook and Line Lift Net
	Selar crumenopthalmus		Sub-Surge Zone	Surround Net Hook and Line (juveniles)
Snappers	*Aprion virescens*	uku	Sub-Surge Zone	Hook and Line
Goatfishes	*Mulloidichthyes flavolineatus*	weke 'a'a	Surge Zone	Net Spear Hook and Line (juveniles)
	M. vanicolensis	weke 'ula	Sub-Surge Zone	Net Spear Hook and Line
	Parupeneus porphyreus	kumu	Surge Zone	Spear Trap

Source: See Appendix A, page A.3-30

TABLE 3

AVERAGE SEASONAL CATCH (IN POUNDS)
OF MAJOR COMMERCIALLY VALUABLE MARINE LIFE
IN THE KAHE REGION

F I S H

Local/Common Name	Scientific Name	Catch Per Season (lbs.) Jan.-June	July-Dec.
Aku (Skipjack Tuna)	*Katsuwonus pelamis*	128,110	178,080
Ahi (Yellowfin Tuna)	*Thunnus albacares*	10,460	19,175
Akule (Bigeye Scad)	*Selar crumenophthalmus*	9,354	5,350
A'u (Black Marlin)	*Makaira indica*	3,494	7,280
Hahalu (Juvenile Bigeye Scad)	*Selar crumenophthalmus*	2,283	4,905
Mahimahi (Dolphinfish)	*Coryphaena hippurus*	3,673	2,947
A'u ki (Striped Marlin)	*Tetrapturus audax*	2,564	3,221
A'u (Blue Marlin)	*Makaira nigricans*	2,096	2,710
Ta'ape (Blue-Lined Snapper)	*Lutjanus kasmira*	1,370	1,931
'O'Io (Bonefish)	*Albula vulpes*	1,416	731
Weke (Yellowstripe Goatfish)	*Mulloidichthys flavolineatus*	1,179	1,639
Weke'ula (Red Goatfish)	*Mulloidichthys vanicolensis*	789	1,401
"Opelu (Mackeral Scad)	*Decapterus macarellus*	336	1,375
Ulua (Jack)	*Caranx* spp.	1,298	871
Kawakawa (Little Tuna)	*Euthynnus yaito*	445	1,364
Ono (Wahoo)	*Acanthocybium solandri*	948	932
Kala (Unicorn Surgeonfish)	*Naso unicornis*	540	769
Palani (Surgeonfish)	*Acanthurus dussumieri*	389	645
Menpachi (Squirrelfish)	*Myripristis* sp.	262	560
Kumu (White-Spot Goatfish)	*Parupeneus porphyreus*	431	281
A'u (Shortbill Spearfish)	*Tetrapturus angustirostris*	426	89
Awa (Milkfish)	*Chanos chanos*	357	198
Mamo (Sargeant Major)	*Abudefduf abdominalis*	257	206
Ahi (Bigeye Tuna)	*Thunnus obesus*	36	233
Kahala (Amberjack)	*Seriola dumerilii*	220	59
'Opakapaka (Snapper)	*Pristimoides filamentosus*	156	238
Pualu (Ringtailed Surgeonfish)	*Acanthurus xanthopterus*	177	58
'Omilu (Blue Jack)	*Caranx melampygus*	54	144
Uhu (Parrotfish)	*Scarus* spp.	125	59

I N V E R T E B R A T E S

Local/Common Name	Scientific Name	Catch Per Season (lbs.) Jan.-June	July-Dec.
Ula (Spiny Lobster)	*Panulirus* spp.	161	113
He'e (Octopus)	*Octopus* spp.	99	381

L I M U

Local/Common Name	Scientific Name	Catch Per Season (lbs.) Jan.-June	July-Dec.
Limu (Seaweeds)	All species	1,472	913

Source: Hawai'i State Division of Fish and Game records of commercial catch for statistical area 402 (inshore) and area 422 (offshore). 1975 to 1980 average.

A second, but important, recreational fishery practiced from small boats in the Kahe region is night handlining for menpachi. This fishing activity is conducted in relatively shallow depths (30 feet) and generally on the darkest nights of the month. Since dark nights produce the highest catches of this nocturnal feeder, fishing activity is generally limited to two weekends per month when the moon phase is suitable. Table 4 indicates the menpachi and associated species taken by one recreational handline fisherman over the 1974 to 1980 period.

As noted in the introductory section (1), larval fish survey data collected as part of this study is included in Appendix B.

TABLE 4

CATCH OF MENPACHI AND ASSOCIATED SPECIES (POUNDS)
BY ONE RECREATIONAL HANDLINE FISHERMAN
KAHE OTEC REGION
1974 to 1980

Month	1974	1975	1976	1977	1978	1979	1980
January	--	1	15	--	--	--	--
February	140	--	30	15	--	--	--
March	45	--	100	50	--	--	70
April	52	--	30	80	75	--	165
May	178	130	80 (8)	--	--	--	70 (10)
June	--	30	20	35	30	--	--
July	--	180 (10)	100	100 (8)	--	--	--
August	230	290	90 (3)	--	155	--	--
September	210	35	40	155	50	50	325
October	5 (16)	45 (10)	--	--	50	60	90
November	78 (7)	--	80 (10)	--	85	--	--
December	35	--	--	--	--	--	--
Total Annual	973 (23)	711 (20)	585 (21)	435 (8)	445	110	720 (10)

Note: Figures in ( ) indicate catches of associated species.

Source: See Appendix A, page A.3-34

SECTION 4

IMPACTS OF OTEC DEVELOPMENT

In the previous two sections of this report, various physical, chemical and biological oceanographic and fisheries investigations pertaining to the establishment of an OTEC facility in the Kahe Point study area have been reviewed. In this section, the various potential oceanographic and visual/aesthetic impacts are discussed in relation to four different types of OTEC facilities that appear to be applicable to the Hawaiian setting.

The four types of OTEC facilities are: (1) an offshore vessel design that is permanently moored in one location, with a long cold water pipe extending 3,000 to 6,000 feet below the vessel (power generated on-board is transmitted via a submarine cable system to the shore); (2) an onshore OTEC facility similar to the present Seacoast Test Facility (STF) located at Keahole Point, Hawaii. This type of facility has a cold water pipe extending offshore to the depth required to obtain the desired ΔT[1]; (3) a "Texas Tower" or derrick-type facility as described in Appendix C; and (4) a mobile-type vessel that is capable of moving from location to location seeking the optimum ΔT conditions (such a vessel could produce fuels such as liquid hydrogen or ammonia or produce specific products from the sea water, such as fertilizers).

Each of these four potential designs would produce a variety of impacts on the marine environment. Some of these impacts would be common to all four designs, others would be specific to a specific design. These impacts are discussed below for each of the four different types of OTEC facilities.

(1) NOTE: ΔT refers to the warm water-cold water temperature differential required to run an OTEC plant. See <u>OTEC For Oahu</u> report for plant operation characteristics and requirements.

To date, one of the least examined aspects of siting OTEC facilities in Hawaii has been the visual or aesthetic impacts of either an offshore or onshore plant. This lack of examination has been justified to some extent in that only general descriptions of future OTEC facilities have been available and their mooring or onshore placement locations have not been specifically determined. However, it appears prudent to consider the visual/aesthetic factors at this time to assure that they are as thoroughly considered as other environmental factors.

In an effort to initiate a preliminary analysis of the visual and aesthetic factors, it was determined that, at present, offshore oil and gas exploration and drilling platforms most closely resemble future OTEC facilities. This determination is reinforced by the submission of a proposal by General Electric Company to the U.S. Department of Energy (DOE), in response to DOE's OTEC 10/40 MW Pilot Plant Program Opportunity Notice (PON). A "Texas Tower" type facility is proposed to be established off the Kahe Point area. This tower would presumably have a cold water intake pipe extending offshore for some distance to attain the water temperature differential (ΔT) required to generate electrical power. The power would then be transported to shore via a submarine cable and fed into the Oahu electrical grid system.

A. Offshore Fixed or Mobile Floating Platforms

1. Oceanographic and Fisheries Impacts

The principal potential marine environment impacts resulting from mobile or moored platforms are those associated with the cold and warm water effluents. In this regard there are two basic potential impacts, (1) thermal and (2) chemical.

The potential thermal impact would be the effect of the cold water discharge on tropical shallow-living marine organisms. Although additional studies are required to fully quantify this potential impact on marine organisms, a few studies have been conducted on the thermal tolerances of tuna. For example, yellowfin tuna are fished in waters with surface temperatures ranging from 73 to 90 degrees F, and skipjack tuna in waters ranging from 66 to 73 degrees F. During the experiments conducted on OTEC-1 the discharge water was approximately 64 degrees F, which is below the preferred limits of either yellowfin or skipjack tuna. However, the cold water effluent effects would most likely be dependent upon the volume of the effluent and the rapidity with which it mixes with surrounding waters. Based on the catch data discussed previously for the OTEC-1 vessel, it would appear the effluent had no negative impact on the distribution of tuna around the vessel.

Another potential thermal impact factor would be that associated with the mixing rate of the cold water effluent with the surrounding waters. The cold water, if not mixed rapidly, could act as a thermal barrier to the recruitment of sessile organisms and their attachment to either the fixed or mobile platform. A major factor affecting this impact will be the areal extent and depth of the effluent plume. Additional studies regarding thermal effects appear to be required before the positive or negative nature of these effects can be stated with any degree of reliability.

The potential chemical impact would be that associated with the chemical cleaning of the warm and cold water pipes and the heat exchangers. Based on the latest available information (HNEI, 1982) it appears that very low levels of chlorination (0.025 to 0.050 ppm chlorine for one hour per day) effectively controls the growth of fouling films on the warm water components while biofouling does not appear, at present, to be a problem on the cold water components. The introduction of bound or free chlorine in the warm water effluent, since it does act as a biocide, could potentially adversely affect the micro and macro biota in and around the effluent plume. However, the extent of this potential effect in Hawaiian or other subtropical and tropical areas is unknown at present due to the lack of research. This situation is being corrected with the initiation of research activities through the Natural Energy Laboratory of Hawaii and Hawaii Natural Energy Institute. Additional studies are required, however, before definitive statements regarding the effects of chemical biofouling control methods on the water chemistry and biota surrounding offshore fixed and/or mobile floating OTEC plants.

Possibly acting as positive impacts, offshore fixed or floating types of OTEC facilities, act as fish aggregating devices (FAD's) and/or artificial reefs, as do oceanic flotsam, and could serve to attract commercially harvestable crops of fish. FAD's and artificial reefs have had a positive effect on both commercial and recreational fishing activities in Hawaii. During the deployment of both Mini-OTEC and OTEC-1 off the Big Island, both commercial and recreational fishermen utilized these temporary FAD's and artificial reefs to economic advantage. For example, during operation of OTEC-1, an average of ten small boats per day were observed carrying out fishing activities (primarily handlining by commercial vessels and trolling by recreational vessels) around the vessel over a 75-day period. Catches of large, high value (i.e. $3.00 to $5.00 per pound) tuna were estimated to be about 500 pounds per vessel per trip to OTEC-1. Similarly the small-boat tuna handline fleet out of Kona is estimated to have harvested a total of 2.5 tons per day of fishing. Assuming a wholesale (ex-vessel) value of at least $3.00 per pound, the Kona handline fishery probably generated gross revenues of at least $15,000 per day as a direct result of OTEC-1. The pre-OTEC-1 catch value is not known, however, the size of the fishing fleet has increased from 30 to 40 boats to about 120 boats.

Similar economic effects could be expected from a mobile OTEC plant. For example, the Pacific Tuna Development Foundation (PTDF) began exploratory surveys in 1976 in an effort to expand the U.S. purse seine fishery to the central and western Pacific Ocean. These surveys and similar type surveys conducted by Japanese fishermen have indicated that the generally wildly erratic behavior and far ranging schooling habits of pelagic tuna are tempered considerably by the presence of flotsam. The schools congregate around floating, drifting objects and are much more easily netted and brought to market. Purse seining in the vicinity of an OTEC platform would be analogous to flotsam-associated purse seining presently practiced by both U.S. and Japanese fishermen in the central central and western Pacific or to the raft fishing practiced in the Philippine Islands.

2. Visual/Aesthetic Impacts

The visual/aesthetic impacts of either a mobile or moored OTEC facility in Hawaii are likely to be minimal. In the case of a mobile facility, it is probable that the plant would "graze" out of sight of the islands. The products produced by the facility would be transported to Hawaii by ships similar in appearance to the numerous cargo or oil supply ships that regularly visit Hawaii. In the case of a moored platform, it is possible that the platform would be situated far enough offshore (five miles or more) to be almost unnoticeable from the shore. Should the platform be moored between three and five miles offshore and have a super-structure or components extending 150 feet above the water, the entire facility would be visible and components discernible. However, the plant would appear much smaller than actual size and would probably be perceived as a ship coming over the horizon. The closer to shore the plant is moored, the more discernible the plant components will be and the more visually intrusive the plant may appear.

B. Tower Type OTEC Facilities

1. Oceanographic and Fisheries Impacts

The impacts of the tower or derrick-type facility on the marine environment would be similar to those described above. That is, the tower would probably act as an artificial reef, drawing both commercially and recreationally valuable marine organisms to the immediate vicinity of the plant. However, since a similar type facility has not been placed in Hawaiian waters, estimating the species density and diversity associated with such a structure off Kahe Point would be conjecture. An analogy may be possible from oil platforms placed in subtropical water areas similar to Hawaii. In the Gulf of Mexico, various researchers have found that there is a definite fish aggregating effect of oil platforms.

Impacts also will result from the construction activities related to the cold water pipe or the submarine electrical cable connected to the tower, if they require dredging or blasting for placement purposes. This construction activity could seriously impact the biota in the immediate area. However, based on studies conducted around the HECO Kahe Generating Station, it appears that construction activities may have a transitory effect and that both the motile and sessile biota return within a reasonable period of time. This same effect appears to be occurring in and around the Honolulu International Airport Reef Runway (Chapman, 1979).

Similarly there is the potential impact regarding the effect of the cold and warm water effluents. If not mixed rapidly, the cold water effluent could act as a thermal barrier to successful recruitment of numerous coral reef dwelling and forming species. The potential warm water effluent impact would be that associated with chemical control of biofouling as described above. Also, as with other OTEC facility types, the entrainment and impingment of marine organisms will be an impact of the tower-type OTEC plant.

2. Visual/Aesthetic Impacts

A field investigation of offshore platform construction activities and in-place platforms was conducted in Scotland and elsewhere in the United Kingdom (U.K.) as well as in the southwestern United States gulf coast states. Additionally, a literature review regarding the visual/aesthetic factors of offshore platforms was conducted and interviews with cognizant public agency and private organization personnel were held. The complete results of this work are described in Appendix C to this report.

In general, it is thought that one of Hawaii's greatest assets is the visual beauty of both our mountain and ocean vistas. The erection of a platform that may be as much as 100 feet above the surface of either the surrounding land or ocean area may result in adverse reactions from both residents and tourists. Although it is unlikely such a tower would be required on land, a tower would be required offshore. The potential adverse visual impacts of these towers can be partially mitigated through various architectural treatment schemes. However, the effectiveness of these schemes would have to be reviewed by the Oahu community before their value could be determined.

It is likely that the initial visual impact would occur during the construction of a tower-type OTEC facility, assuming construction were accomplished in Hawaii. It is likely that any tower-type OTEC facility, if constructed in Hawaii, would be one of the largest construction projects performed in the State and would result in one of the larger visual impacts in the State. Tending to offset the temporary visual impact of construction would be the economic impact of such construction. For example, towers or platforms similar to those described in Appendix C, are estimated to cost approximately $1.5 billion (see Appendix C, Literature Cited, Edmiston, 1981).

Once in place, such platforms as described above will be visible from great distances. The visual impact would be greatest from nearby beaches, headlands and mountains. Since the ocean bottom off Oahu drops fairly sharply (for example, off Kahe, water depths approximately one mile offshore reach 330 to 650 feet and 1.5 miles offshore the water depth reaches 1,600 feet), it is likely that the tower or platform-type facility would be within 0.5 mile of the shoreline and extend approximately 100 feet above the water surface.

In an effort to mitigate many of the above noted potential adverse visual impacts, both during and after construction, Scotland, for example, has adopted specific environmental guidelines. These guidelines specify those areas in which construction and support activities may take place and those in which construction activities may not take place. Other areas have been designated for some support activities, such as pipeline terminal areas or pump station areas, but limit these types of activities. An environmental control system similar to that developed in Scotland may be applicable to Hawaii. However, given the relatively few suitable Hawaiian harbor locations, construction and/or support activities may be limited to existing or presently planned harbors.

C. Onshore OTEC Facilities

1. Oceanographic and Fisheries Impacts

The effects on the marine environment of an onshore OTEC facility will be primarily limited to the placement of the cold water pipe and the cold and warm water effluent discharge. The effects of bringing the cold water pipe ashore would be similar to those discussed for the derrick alternative. The cold water effluent, if discharged close to the plant and shoreline would, however, probably have a greater impact than for the derrick-type facility.

Studies conducted on the effects of temperature on Hawaiian reef corals indicate that a decrease in the natural water temperature would be more harmful than a similar increase in temperature (Jokiel and Coles, 1977). For example, a lower lethal limit of 64 degrees F, or the same as the OTEC-1 discharge temperature, has been established for some Hawaiian corals. Additional studies of thermal change effects on coral reef organisms appear to be required before definitive or quantitative answers can be given. Similarly, the effects of chemical biofouling control and the effects of those chemicals on the water chemistry and biota require additional study.

One final potential impact on the marine environment of any of the fixed-type OTEC facilities that should be researched further is the potential for increased ciguatera incidences. Several hypotheses have been offered regarding the causes of ciguatera outbreaks. However, it does appear that marine construction activities may trigger blooms of dinoflagellates that have been implicated as being the source of the toxin. To date, it is not possible to predict whether or not a given construction activity in the marine environment will lead to increased incidences of ciguatera. Therefore, it appears prudent to conduct a ciguatera monitoring program during the construction period.

2. Visual/Aesthetic Impacts

The visual/aesthetic impacts of an onshore OTEC facility most likely will be minimal. The OTEC facilities probably will be colocated with existing power generating stations, similar to that presently proposed by Ocean Thermal Corporation for the Kahe Generating Station. Land based OTEC facilities can be architecturally designed to fit in with their surroundings and screened through the use of landscaping.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK AREAS

The preceding sections of this report have identified the literature reviewed and briefly discussed potential environmental parameters and impacts relevant to the establishment of an OTEC facility in the Kahe Point study area. These parameters and impacts have included the existing chemical and physical oceanographic characteristics of the area; the entrainment, impingement and entrapment of marine organisms; the commercial and recreational fisheries of the region; and the visual/aesthetic parameters relating to the establishment of an OTEC facility both on and offshore the Kahe region. From the foregoing it would appear that the following preliminary conclusions can be drawn:

Physical Oceanography:

It is recognized that there would be changes to the overall characteristics of the physical oceanographic conditions in the vicinity of OTEC facilities. However it appears that an OTEC facility in the Kahe region would have minimal impact on the physical oceanographic characteristics, except for potential effects of the cold water effluent as discussed below. It would also appear that the physical oceanographic factors will impact on the design and placement of the OTEC facility, especially in view of the apparent highly variable current patterns and wind and wave regime.

Chemical Oceanography:

The chemical oceanographic effects of an OTEC facility on the surrounding waters do not appear to be fully understood at this time. Various OTEC-1 and other laboratory investigative programs indicate that the chemical oceanographic effects may be limited in extent and may not produce serious short or long-term problems. For example, it has been hypothesized, for an inshore or onshore plant, that the cold water effluent, which most likely will be nutrient rich, will have an adverse effect on the surrounding area. However, the effluent effect is dependent upon (1) the discharge depth, i.e. whether it is within the upper "mixed" layer of the water column or below the mixed layer, and (2) whether the effluent contains cold water only or is mixed with the warm surface water effluent. If the cold water discharge is into the upper photic zone, biostimulation, e.g. algae blooms, could occur. However, there appears to be a question of whether this biostimulation would ever be measurable since dispersion and mixing would probably occur rapidly. At present, most OTEC researchers believe that measurable effects will not occur for small OTEC plants, e.g. less than 100 MW capacity. Larger OTEC plants may cause measurable effects, but the characteristics of these effects are presently unknown. For an offshore plant, it is possible that increased biostimulation could produce positive effects through the increase of available food supplies for higher trophic levels. However, at present these are hypotheses only and additional biostimulation studies are underway both in the Kahe OTEC study area and at the Natural Energy Laboratory of Hawaii (NELH).

In the preceding discussion, it is assumed that means other than chemical treatments will be utilized to clean heat exchanger tubes or any other plant component. However, as noted previously, based on the preliminary results of research conducted on OTEC-1 and at NELH, it appears that chemical cleaning of heat exchanger tubes is the most efficient and least costly cleaning method. The studies conducted indicate that for the cold water system, very little cleaning is required due to the lack of biofouling. In the warm water system, cleaning is required more frequently than the cold water system, but the levels of chemicals used (primarily chlorination) are low (0.025 to 0.050 ppm for one hour per day) are just barely detectable in the effluent. However, additional laboratory and field research work is required to quantify the effects of chemical biofouling control.

Biological Oceanography:

Based on the literature reviewed and field studies conducted for this report, it appears that the greatest effects of establishing an OTEC facility in the Kahe region will be on the marine biota of the area. These effects will be evidenced in both the construction and operation phases.

During construction, depending on the type of facility constructed, the biological impacts could range from transitory to long term. Transitory effects could result from dredging activities during placement of an offshore platform and/or the placement of the cold water pipe and power transmission cable. Dredging activities would result in the removal of inshore organisms as well as increasing the levels of suspended solids in the water column. Another effect could be increased incidences of ciguatera poisoning. In general, a wide variety of fishes (snappers, groupers, jacks, barracudas, surgeon fishes and wrasses) are the commonly caught species of fish that people eat and from which they contract the poisoning. Ciguatera does not affect the fish themselves.

Plant operation environmental effects could result from the entrainment, impingement and entrapment of fish and larval marine organisms in the warm and cold water systems; the establishment of cold water "cells" near the cold water effluent discharge pipe and a resultant reduction in nearshore species abundance and diversity through adverse thermal effects; and potential alteration of the water chemistry around the plant. Positive factors expected from moored, mobile or derrick-type plant designs are the effects of creating a fish aggregation device or artificial reef; increasing the population levels of phytoplankton (fish and invertebrate food) in the water column through the biostimulation effects of the cold water effluent as discussed above; and the attendant potential increased commercial and recreational fish catch possibilities. This latter factor may be negated if overfishing reduces population stocks below the level at which sustained populations can exist.

Visual/Aesthetic Factors:

The potential visual intrusion of an offshore OTEC facility is difficult to assess at this time due to the lack of comparable facilities in Hawaii. However, initial indications are that construction activities of tower type facilities could be viewed with adverse public reaction. Plant placement and operation offshore of Kahe Point, similarly, may result in adverse public sentiment. However, architectural treatments, such as screens to hide OTEC plant components or landscaping, may be possible, somewhat mitigating visual intrusion factors.

Onshore facilities, especially if they are colocated with existing power generation facilities such as the Kahe Generating Station, are likely to have little, if any, visual/aesthetic impact. Onshore facilities can be screened through landscaping and architectural design should this be required.

As a result of the literature reviews and field investigations conducted for this report, it appears that initial studies have been performed for the major environmental effects that could result from the establishment of an onshore or offshore OTEC facility in the Kahe region. There is a considerable body of information available for the nearshore marine biological, chemical and physical characteristics of the area. Similarly, two baseline environmental surveys of the offshore area have been performed (see Figure 4) and provide data that is probably more than that required for environmental assessment purposes. However, it appears that additional site specific information in all oceanographic fields as well as additional regional information is required for environmental impact statement (EIS) purposes for a specific OTEC facility proposal. The following lists those areas that appear to require additional study for EIS and decision-making purposes:

ADDITIONAL STUDIES REQUIRED RELEVANT TO
OTEC DEVELOPMENT IN KAHE POINT STUDY AREA

Environmental Parameter	Study Required	Remarks
1. Meteorology	Regional and site specific on and offshore wind data collection.	Data collected will feed into and be correlated with oceanographic data.
2. Physical Oceanography	(1) Regional and site specific wave, tidal and current data.	(1) Data should be collected for a one-year period, on inshore shelf, seaward slope and at slope break.
	(2) Cold and warm water effluent plume dispersion modeling and field studies.	(2) Data to be correlated with chemical and biological data for impacts analyses.

3.	Chemical Oceanography	(1) Regional and site specific water quality data collection for organic and inorganic nutrients and other water quality parameters listed in State Water Quality Regulations.	(1) Data should be collected at least three times per year to identify seasonal coverage, sampling should be conducted from surface to 600 m depth. Results would be used for correlation with existing standards and to identify construction and operation impacts.
		(2) Cold and warm water effluent plume sampling.	(2) To be used to assess impacts of plume.
4.	Biological Oceanography	(1) Regional and site specific phyto and zooplankton	(1) To be correlated with physical and chemical oceanographic factors.
		(2) Detailed site specific larval fish surveys.	(2) To provide baseline data.
		(3) Cold and warm water effluent plume studies on micro and macro marine organisms.	(3) To be used to identify operation impacts.
		(4) Benthic biota surveys for site specific cold water pipe and power transmission cable placement.	(4) To be used to identify construction impacts.
5.	Fisheries	(1) Adult commercial and recreational fish population density and diversity studies.	(1) To be used to identify facility placement impacts.
		(2) Ciguatera Monitoring Studies.	(2) To be used to determine correlation between construction/operation of OTEC plant if ciguatera outbreak occurs.

6.	Geotechnical Investigations	Site specific sediment sampling and subsurface coring.	To be used to identify construction impacts.
7.	Visual/ Aesthetics	(1) Land-Use Studies (2) Community Attitudinal Studies (3) Architectural Treatment/Design and Landscape Design Studies	Information collected to be used to determine community attitudes and the positive/ negative impacts of OTEC development. Data would also be used to identify and establish institutional/legal framework and possible visual treatment for on and offshore facilities.

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APPENDIX A

PART 1

Literature Review of the Shoreline and Nearshore Environments of the Kahe OTEC Region

PART 2

Literature Review of the Physical, Chemical and Biological Oceanographic Parameters Pertinent to OTEC Development at Kahe Point, Oahu

PART 3

Literature Review Relevant to the Impacts of OTEC Development

Prepared by AECOS, Inc. for Parsons Hawaii
August, 1981

PREFACE

The purpose of this review is fourfold: (1) to bring up to date an existing compilation (O'ahu Coral Reef Inventory) of the known information describing shoreline and nearshore environments between Kane'ilio Point and Barbers Point (leeward O'ahu); (2) to compile the known oceanographic and geophysical information describing oceanic environments (at depths over 150 feet) offshore of the same area; (3) to estimate the impacts associated with the development and operations of an OTEC plant on benthic and pelagic fisheries; (4) to evaluate the adequacy of the existing information within the context of environmental concerns related to development of an OTEC facility within the area.

Dr. David A. Ziemann served as project manager and, with Paul Bartram, was responsible for the review of existing pertinent literatre. Dr. Richard E. Brock assisted in the assessment of fisheries potential; Kal Ho assisted in the effort to quantify the existing fisheries. Their technical assistance is greatly apreciated.

The text of the report was written onto magnetic diskette, edited, formatted, and printed using Digital Research® CP/M and MicroPro® WordStar software.

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INTRODUCTION

Part B (the text) of the O'ahu Coral Reef Inventory (OCRI) contains extensive descriptions of the coast, shoreline, and offshore areas of the Island of O'ahu, arranged in a sequential series based on the 93 sectional maps comprising Part C (The OCRI Atlas, in prep.). Thus, for each of the 93 maps encompassing the coastline of the Island of O'ahu, an accompanying description is provided in Part B. Each description covers the topics of physiography (geography and geology), flora and fauna (results of biological surveys), water quality, historical and archaeological sites, uses, and a listing of studies conducted in the coastal section. Each map and MAP description is assigned a number and a name, the latter based on a prominent place name within the area covered by the map. MAP descriptions are arranged subsequentially in the text, beginning with MAP 1 covering the Makapu'u area and running counter-clockwise around the coastline of the Island. Placement of the maps is shown in figures in the text which usually follow a general description of the coastline of each of the six O'ahu Districts which border on the ocean.

The text of Part B is purposely brief on individual subjects to allow maximum presentation of information; users interested in detail on any particular point are encouraged to seek original sources, including in some cases other Parts and Appendices of the OCRI document. Sources are credited throughout the text by numbers appearing in parentheses and listed in the References Cited at the end of Part B. One of the tasks of the OCRI Project was to compile a listing of all recent studies conducted in marine and coastal areas around O'ahu. Much of this source material consists of unpublished material and so-called "grey" literature -- reports printed and distributed in limited numbers. On the other hand, much valuable literature of a general nature (that is, published studies which do not contain site-specific information) may not be cited in Part B.

Each sectional MAP description was written using a standard format which dictates where in the text specific facts and kinds of information appear. It should be appreciated, however, that the decriptions are intended to be site specific and therefore gaps in the generally available knowledge about locations along and off the coastline of the Island may appear as obvious omissions. No concerted effort was made in the MAP descriptions to extend knowledge about one area to general statements about some larger section of the coast. Nonetheless, a certain amount of extension by implication is unavoidable, and readers are cautioned of this fact.

The Kahe OTEC study area is bounded by Kane'ilio Point to the northwest and Barbers Point to the southeast. This area is described by portions of MAP 61 and MAP 62-69. The shoreline is backed by residential areas at the northern extreme and by industry at the southern extreme. The area between is in agricultural use.

OCRI has been expanded and updated for this literature review and summarizes virtually all biological and other types of studies of any relevance to assessment of shoreline and nearshore environments (to a depth of approximately 150 feet) in the study area. OCRI includes descriptive information from a major popularized study of the natural history, current status and uses of O'ahu beaches (Clark, 1977).

No single survey encompasses the entire study area. Marine surveys have focused on four localities within the general area of concern. By far the most comprehensive data base exists for the area off Kahe Point, as a result of years of monitoring by the Hawaiian Electric Co. of environmental impacts related to the Kahe power generating plant.

Kahe Power Generating Station

Since the beginning of operation of the Kahe power generating station in 1963, over 50 reports describing the marine environment nearby have been prepared for or by the Hawaiian Electric Company.

The general condition of the nearshore marine environment off Kahe was described in reports by Marine Advisors (1964), B.K. Dynamics (1971), and URS Research Co. (1973). Results of these and other studies were summarized in an environmental impact assessment prepared by Stearns-Roger, Inc. (1973) for the expansion of the Kahe facility to 6 generating units.

Monitoring programs to establish baseline conditions for the marine biological environment at Kahe were begun by the Hawaiian Electric Company's Environmental Department in 1973 and have continued to the present time. Baseline conditions preceding expansion of the Kahe Station to five units and subsequent construction and operation of the offshore outfall are described in Coles and McCain (1973) and Coles and Fukuda (1975). An interim report describing conditions resulting from outfall construction was prepared by Hawaiian Electric Company in November 1976.

Because of the potential entrainment of nearshore sand indicated by a impact assessment for Kahe Units 5 and 6 (URS Corp., 1973; Stearns-Roger, Inc., 1973), a program monitoring beach profiles and offshore sand reservoirs was established in 1973-74 by the R. M. Towill Corp. and continued from 1976 to present (R. M. Towill Corp., 1974, 1977a, 1977b, 1979, 1980a, 1980b, 1981). The results of these and other studies related to the marine environmental impact of the Kahe offshore outfall were analyzed in the 1977 NPDES Final Report (McCain, 1977).

The quantity (and, in some cases, the quality) of information declines in both directions from Kahe Point. Major surveys have also been conducted for assessment of impacts due to the barge harbor at Campbell Industrial Park, and the Standard Oil Refinery at Barber's Point. An area fronting West Beach approximately one-third mile southeast of the Kahe power plant was surveyed as a potential marine life conservation district. Some impact assessments have relied on data collected in previous assessments and have added little new information. Many other sources of information are useful for their general observations but lack a quantitative data base.

Previous comprehensive literature reviews which considered the marine environments of the Kahe OTEC study area are:

* Bathen, K. H., and A.G. Cropper, 1971. Literature review of available terrestrial, meterological, and oceanographic information pertinent to the area around Barbers Point, Oahu, Hawaii. Prep. for Industrial Bio-Test Laboratories, Inc. Northbrook,

Illinois. 142 p. + appendices.

* Bienfang, P. K., and R. E. Brock, 1979. A review of pertinent literaure of the nearshore communities of macrobiota in the Barbers Point to Kahe Point region on Oahu, Hawai'i. 45 p.

Summary of Environmental Impacts

Although currently under stress from sand abrasion (resulting from a major Kona storm in January 1980), the coral communities fronting the area between Kahe Point and the Campbell Barge Harbor are well-developed and diverse. Very few other nearshore areas around the island of O'ahu equal the Kahe-Lanihokonua area in terms of coral-rich bottom. Environmental impacts along the coast between Kahe and the Campbell Industrial Park are localized and minimal. Most of the hinterland is in agricultural use or is lying fallow. Neither use has any obvious or long-term adverse impact on nearshore environments. No perennial streams drain into the ocean, but an old stream bed between Kahe Beach Park and Brown's Camp discharges after heavy rainfall. Runoff occurs from a few other normally dry channels following episodic heavy rains. Although storm-induced runoff causes inshore waters to become noticeably turbid, the effect is temporary, and water clarity is restored within a few days.

Previous biological assessments of impacts to the Kahe OTEC study area have been limited to areas of industrial development such as the Kahe power generating facility and the barge harbor serving Campbell Industrial Park. Information describing the nature and magnitude of impacts arising from the Standard Oil

Refinery at Barbers Point does not appear to be available. Conoco-Dillingham (1972) simply state that the refinery is not expected to have any negative impacts on the nearshore marine environment.

In the area fronting the Campbell Barge Harbor, negative impacts are confined to the dredged entrance channel and seaward for a distance of about 100 m. The primary impact is a change in the bottom from a limestone platform to rubble resulting from dredging. Rubble bottoms are not favorable for coral recruitment and growth, and associated marine life. Both fish diversity and coral diversity and abundance are greater in areas adjacent to the dredged channel than in the channel itself (Environmental Consultants, Inc., 1975).

The Hawaiian Electric Company's facility at Kahe Point consists of five oil-fired steam electric generation units. Cooling water is obtained from a shoreline intake and heated effluent is discharged through an offshore outfall. The areal extent of thermal elevation above ambient water temperature varies with meteorologic/oceanographic conditions. Kona winds appear to enhance the longshore extent of the heated plume. The maximum southerly longshore extent occurred during a period of ebb tide and light south to southwest winds. General tradewind conditions tend to push the plume offshore. All of the studies to date suggest that the effect of the plume is limited in extent.

The Kahe facility does not use any biocides to control biofouling through the system. The only chemical discharges to the water consist of low-volume wastes such as boiler and evaporator blowdown, and treated metal cleaning wastes; these wastes are dischaged at concentrations less than 10^{-3} the concentrations found to be toxic to several species of fish in the area.

The first environmental reports prepared for HECO described the wave regime of the area, estimated the volumes of sand which contribute to the active beach and offshore systems, and discussed the dynamics of sand movement for the region (Marine Advisors, 1964). This Marine Advisors study determined an average volume of 994,000 m^3 (1,300,000 cu. yd.) of sand to be contained in a system between sea level and the 60-foot offshore contour. Another 53,520 m^3 (70,000 cu. yd.) were estimated to make up the beach systems. Although most of the sand recirculates within the system, net movement is to the south with a yearly loss of 1530-2290 m^3/year escaping to deep water estimated by Marine Advisors (1964). This estimate of annual net loss of sand from the undisturbed Kahe system was later revised upwards to 3520 m^3 (4,600 cu. yd.) (URS Research Corp., 1973; Stearns-Roger, Inc., 1973).

Coastal sand surveys indicate that the total increase in the volume of sand deposited off the Kahe Station outfall since 1976 was around 13,700 m^3 (17,900 cu. yd.) During 1980, up to 7,424 m^3 of sand per year were deposited by the Kahe outfall and an additional 6,117 m^3 were transported to land (Coles, Fukuda, and Lewis, 1981). These studies indicated substantial seasonal shifts of sand within the area, subject to potential interception or interference by shoreline structures associated with power station development.

Since the operation of an offshore outfall began in late 1976, sand entrainment and deposition offshore of the outfall and subsequent re-suspension and deposition on coral-rich areas to the south of the HECO facility has been the major environmental impact of the power plant (Coles, Fukuda, and Lewis, 1981).

PART 1: LITERATURE REVIEW OF THE SHORELINE AND NEARSHORE ENVIRONMENTS OF THE KAHE OTEC REGION

SHORELINE AND HINTERLAND

The Kahe OTEC study area encompasses the southeastern end of the Wai'anae District (Kane'ilio Point) and the northwestern portion of the 'Ewa District. The Wai'anae volcano, which is very much older than the Ko'olau volcano of eastern O'ahu, has been greatly eroded. Broad, coalesced valleys separated by narrow, discontinuous ridges characterize the western slopes of the Wai'anae Range. Great quantities of alluvium and colluvium fill the valley floors. Upraised reef shelves, probably formed at a time when sea level stood approximately 25 feet above present sea level (Waimanalo Stand), form terraces along the coast and extend inland as the floors of larger valleys. The Wai'anae District is rather arid, and the streams which drain the land flow only intermittently into the sea.

The great age of the volcanic base, representing a long geological period of erosion, the absence of sea level reefs, and the absence of late or secondary volcanics at or near the coast have produced a coastline of broad indentations without offshore islands and possessing few prominently projecting points of coast.

The shoreline alternates between rocky and sandy sections. Rocky sections include occasional basalt outcrops, but are primarily limestone rock of the raised reef terraces. The latter type of shoreline extends along the coast south of Poka'i Bay, including Kane'ilio Point to around Pu'u Ma'ili'ili; around Ma'ili Point; and in front of Nanakuli.

Typically steep, calcareous sand beaches occur at Ma'ili and Nanakuli. Beachrock is prominent in the wave-washed zone along most of the shore (excepting land points).

The 'Ewa District of O'ahu includes most of the south-sloping portion of the broad saddle between the Ko'olau and Wai'anae Ranges and the slopes which drain into the central and southern plain.

An extensive plain south of Kahe Point (the 'Ewa Plain) is an ancient reef structure which presumably formed during the +25 foot (Waimanalo) stand of the sea, although its geological history is complex. The 'Ewa plain gradually rises from sea level to an elevation of nearly 100 feet (30 m) some 4 or 5 miles (6 to 8 km) inland from the coast. The plain is flat except for a few isolated bluffs eroded by Honouliuli Stream. It is composed of calcareous material which has been modified, consolidated, and cemented by dissolution, rain, air, and other weathering processes to form a hard but extremely permeable surface. The karst topography is characterized by small holes which have dissolved out of the limestone and are interspersed with abrupt ridges and irregular surfaces.

Nearly the entire shoreline of the 'Ewa Plain is limestone of the upraised reef. Calcareous beach sand, beachrock, and low cliffs and beaches out into reef rock characterize the coast. A relatively small amount of Wai'anae basalt rock occurs along the shore at Kahe Point.

The coastline is relatively straight, without embayments or prominent projecting points, and runs roughly south from Kahe Point to Barbers Point. Barbers Point Harbor is a man-made embayment constructed to enable barge service to Campbell Industrial Park on the western portion of the 'Ewa Plain. There are no small islets off this coast.

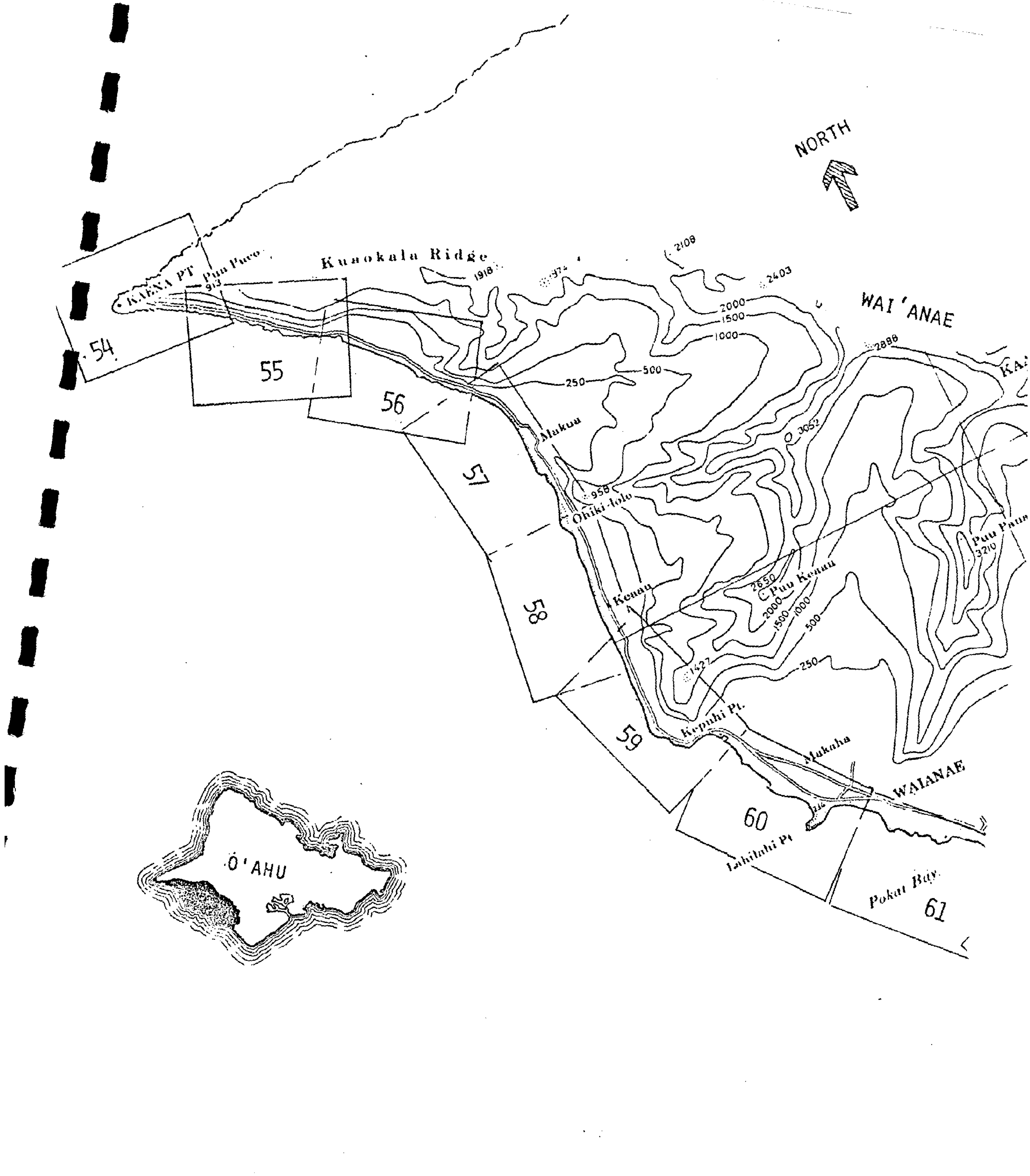
NEARSHORE

No fringing reefs occur along the Wai'anae Coast. A bottom of consolidated limestone predominates in nearshore areas. However, limestone shelves occur off Ma'ili Point and at other scattered locations, although these probably are remnants eroded from older reef limestone rather than constructional features at present-day sea level. North of Kahe Point to Nanakuli, the submerged reef extends to a depth of 30 to 50 feet. Sand-bottomed channels occur off most of the major beaches.

Beginning south of Kahe Point, an exceptionally broad, submerged reef platform slopes gradually seaward. The 30-foot (9 m) depth contour occurs between 2,500 and 6,000 feet (800 to 2,000 m) offshore. The submerged reef is mostly about 25 feet (8 m) deep. Seaward of the 30 to 50-foot (10 to 15 m) depth, the offshore slope steepens to a depth of 65 to 100 feet (20 to 30 m), terminating in a large sand body. A large sand channel cuts through the reef and extends all the way to shore at the Kahe outfall. This sand channel merges with the offshore sand bottom that extends seaward from the reef. The uniformity of the reef slope and smooth reef surface is interrupted by scattered shallow pits filled with sand and limestone boulders.

O'AHU CORAL REEF INVENTORY

The following is an updated version of the O'ahu Coral Reef Inventory (OCRI) prepared for the Army Corps of Engineers by AECOS, Inc. (1980). The text covers the shoreline of leeward O'ahu from Kane'ilio Point to Barbers Point. The region is divided into nine sections, as shown in Figure 1. While there is some overlap between sections, for the most part each section is an independent compilation of existing information on the physiography, flora and fauna, and present uses.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Puu Pueo
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Kuaokala Ridge
1918
2108
2403
2000
1500
1000
500
250
WAI'ANAE
2888
Makua
958
Ohiki-lolo
3052
Keaau
2650
Puu Keaau
Puu Paua
3210
1427
Kepuhi Pt.
Makaha
WAIANAE
Lahilahi Pt
Pokai Bay
54
55
56
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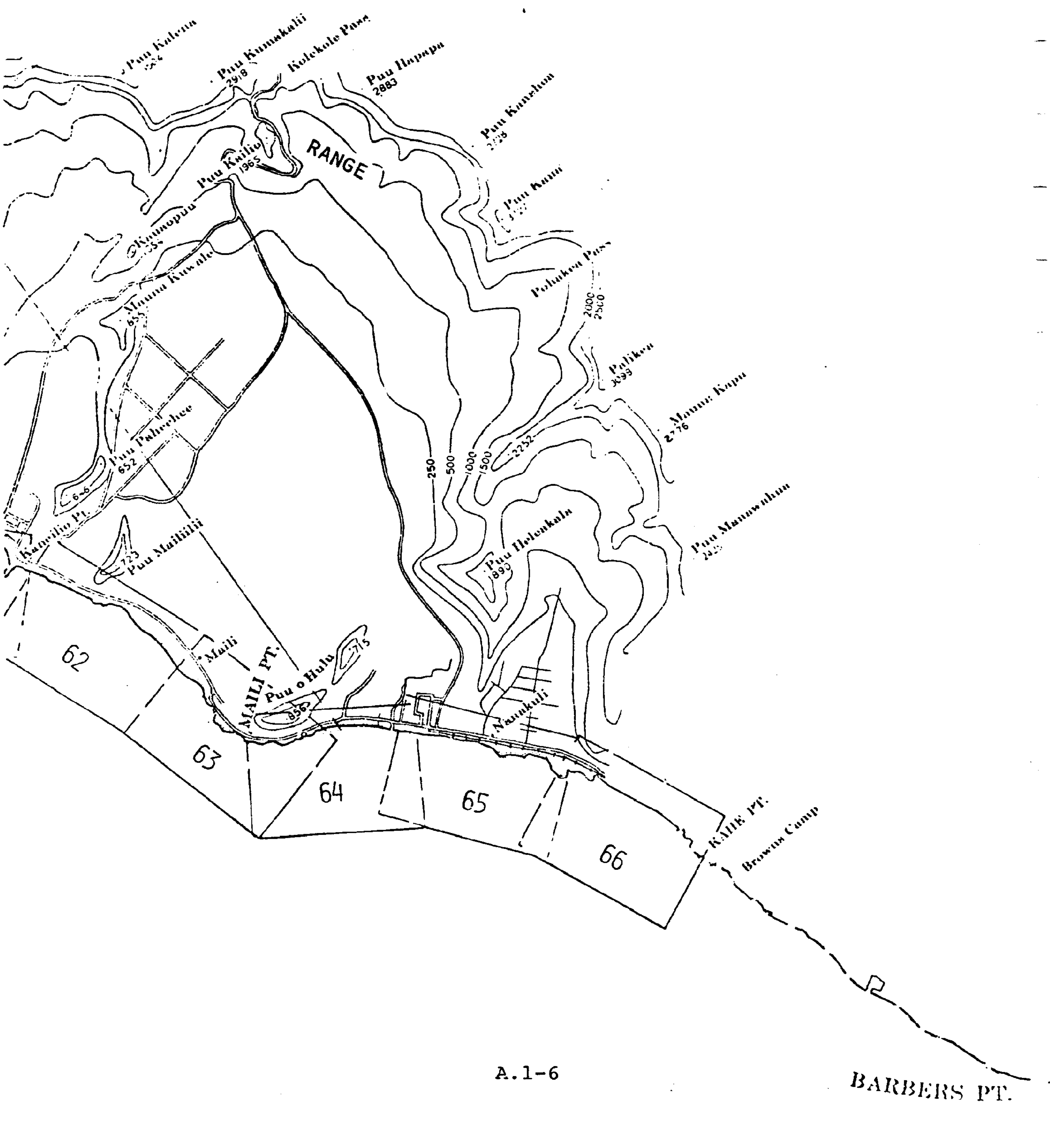
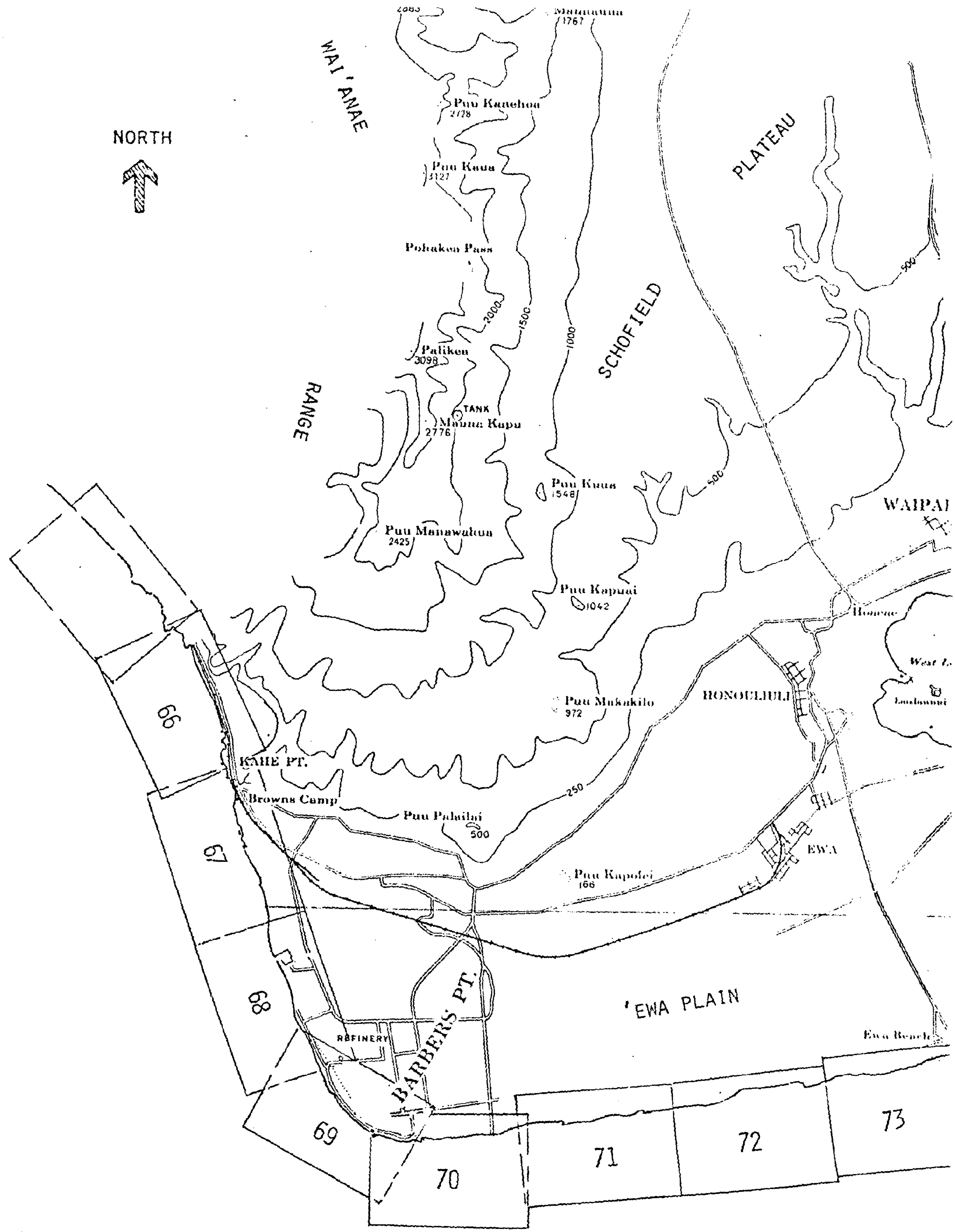
58
59
60
61
O'AHU



Puu Kalena
Puu Kumakalii
2918
Kolekole Pass
Puu Hapapa
2883
Puu Kanehoa
RANGE
Puu Kailio
1965
Puu Kaua
Kaumopuu
Mauna Kuwale
855
Pohakea Pass
2000
2500
Palikea
Mauna Kapu
2776
Puu Pahehee
652
250
500
1000
1500
2252
Kaneilio Pt.
Puu Mailiili
723
Puu Heleakala
1893
Puu Manawahua
Maili
MAILI PT.
Puu o Hulu
856
715
Nanakuli
62
63
64
65
66
KAHE PT.
Browns Camp
BARBERS PT.


NORTH
WAI'ANAE
RANGE
SCHOFIELD
PLATEAU
1767
Puu Kanehoa
2778
Puu Kaua
3127
Pohakea Pass
2000
1500
1000
500
Palikea
3098
TANK
Mauna Kapu
2776
Puu Kuua
1548
Puu Manawahua
2425
WAIPA
Puu Kapuai
1042
Puu Makakilo
972
HONOULIULI
KAHE PT.
Browns Camp
Puu Palailai
500
250
EWA
Puu Kapolei
166
'EWA PLAIN
BARBERS PT.
REFINERY
Ewa Beach
66
67
68
69
70
71
72
73

MAP 61 - POKA'I BAY
(areas southeast of Kane'ilio Point)

- Waianae Quadrangle
- POD, 1:6000 BW, 1:

PHYSIOGRAPHY

COASTLINE

High surf and tsunami flooding are potential hazards along this coast (88). The 1946 tsunami caused runup to 14 feet (4 m) above sea level at Kane'ilio Point (329).

KANE'ILIO POINT - MIKILUA BEACH

Kane'ilio Point is a projection of the raised reef rock that extends inland as a part of the broad plain at Wai'anae. The ancient reef has been attributed to the +25 foot (Waimanalo) stand of the sea which occurred some 40,000 years ago (128;211). Immediately north of the Point is a pocket beach (Poka'i Bay Beach). The shoreline south of Kane'ilio Point was at one time known as Mikilua Beach Park (now consolidated with Lualualei Beach Park - MAP 62). The shoreline is a continuous beachrock formation, behind which there is sand (39;147).

OUTSIDE POKA'I BAY AND OFF KANE'ILIO POINT

A wide, sand-filled channel crosses a complex limestone bottom into Poka'i Bay. Extensive sand deposits at depths greater than 40 feet offshore are part of one of the largest nearshore sand reserves found off the coast of O'ahu (26). Very little sand occurs on the bottom in shallow water off Kane'ilio Point (156).

OFF LUALUALEI BEACH PARK
(See MAP 62)

FLORA AND FAUNA

OUTSIDE POKA'I BAY AND OFF KANE'ILIO POINT

Limestone bottom between -20 and -40 feet (-6 to -12 m) off Kane'ilio Point supports less than 5% coral cover, with _Porites lobata_ and _Pocillopora meandrina_ most frequently observed. Fleshy algae cover 5% of the bottom. The sea urchin, _Echinothrix calamaris_, is the most common macroinvertebrate. Seventeen species of fishes are reported from shallow water (-20 feet). _Pervagor spilosoma_ is by far the most abundant, followed by _Acanthurus triostegus_ and _Thalassoma ballieui_. Only _P. spilosoma_ is recorded from -40 feet (165).

The pen shell, _Pinna semicostata_, is abundant in patches in the extensive sand bottom areas extending between -80 feet (-24 m) and at least -120 feet (-37 m) off Poka'i Bay. Corals are absent and fishes uncommon in this habitat (165).

OFF MIKILUA BEACH
(See MAP 62)

HISTORICAL AND ARCHAEOLOGICAL

KU'ILIOLOA HEIAU

The remains of Ku'ilioloa heiau are present on the extreme tip of Kane'ilio Point. Much of the site was destroyed during World War II (215), but is currently being restored by the Wai'anae Hawaiian Civic Club (382).

USES

KANE'ILIO POINT - OFF POKA'I BAY

The entire coast from Mauna Lahilahi Beach Park (MAP 60) to Lualualei Beach Park is readily accessible and receives heavy fishing pressure. Poka'i Bay - the breakwater and small boat harbor - is a focus of fishing activity. Spearfishing and pole fishing are intensive throughout the area. Net fishing is very common, throw-netting less so. A wide variety of fishes are caught, particularly smaller reef species.

As elsewhere along the Wai'anae coast, ornamental fish collecting is an important activity offshore. Trapping for reef fishes and crustaceans takes place in deeper waters. The bottom off Poka'i Bay is regarded as productive by shell collectors (375). Commercial dive shops run charters to areas offshore. This coast may have potential for offshore sand mining because of major deposits of sand found at depths less than 60 feet (26).

In the summer, the surf break off Kane'ilio Point is occasionally good for board surfing by experts. The rocky shore and strong currents are hazards reported by surfers. Sharks are sometimes sighted in waters in and around Poka'i Bay (86;236).

LUALUALEI BEACH PARK - MIKILUA BEACH

The former Mikilua Beach Park is now consolidated with Lualualei Beach Park (MAP 62). Mikilua Beach is poor for swimming because of a low cliff along the shoreline. Unlike Poka'i Bay and Mauna Lahilahi (MAP 60) Beach Parks, Mikilua is exposed to dangerous surf and currents when winter swells approach from the North Pacific. The park is used primarily by fishermen (39).

STUDIES AND SURVEYS

16 - Bathen (1978): p. 62-64, figs. 15,16,26,27. Compilation and analysis of offshore water circulation data. Additional references.

126 - McVey (1970): Table IV. Summary of fish abundance and number of species at 3 of nine sites (-50 to -85 feet deep) between Wai'anae and Maipalaoa Beach Park (MAP 63).

156 - Oceanic Institute (1976): App. B. Sta. 5 of seven (Summer, 1974) off the Wai'anae coast at which physical, chemical, plankton, and bacteria surveys were conducted. Sta. 4 of six at which fishes, corals, and benthic invertebrates were surveyed in August 1974. Samples 13 and 14 of ninety sediment samples collected along Wai'anae coast analyzed for grain size distribution.

165 - Reed, Kay, and Russo (1977): Transect B of five off Wai'anae. Substratum types, algae, coral, fishes, macroinvertebrates, and micromolluscs surveyed at five depths along each transect line.

MAP 62 - MA'ILI

(MA'ILI, MA'ILI'ILI STREAM, LUALUALEI BEACH PARK, MA'ILI BEACH PARK)

- Waianae Quadrangle
- POD, 1:6000 BW, 1:

PHYSIOGRAPHY

WAI'ANAE AND LUALUALEI VALLEYS

A much eroded and isolated remnant (Pu'u Ma'ili'ili) of the Wai'anae range forms the point called Kalaeokakao, which separates the broad, alluvial filled valleys of Wai'anae and Lualualei (near the coast). The floors of these valleys are comprised of marine sediments and ancient reef formations. Residential areas of Wai'anae occur behind the shore north of Pu'u Ma'ili'ili, and the town of Ma'ili occupies much of the coastal lands across the mouth of Lualualai Valley. (Also MAP 61).

LUALUALEI BEACH PARK

The shoreline of Lualualei Beach Park is beachrock and reef rock along its entire length between Kane'ilio Point (MAP 61) and Kalaeokakao (Point). The backshore, behind the beachrock, is inactive dune sand and old beach ridges (146;147).

MA'ILI BEACH

Ma'ili Beach, one of the longer sand beaches on O'ahu, extends from the outlet of Ma'ili'ili Stream to the mouth of Maipalaoa Stream (MAP 63). Ma'ili Beach has been ranked second of O'ahu beaches in sand volume. Low dunes occur behind the beach. This wide sand beach is broken into three sections by outcrops of beachrock (147). Most of the shoreline is fringed by reef rock at the water's edge. The beach is held at the northern end by a jetty, constructed in 1966 as part of a major stream channelization project to prevent sand from blocking up the mouth of Ma'ili'ili Stream (39).

This section of coast experiences high surf and tsunami flooding (88). Winter storm waves sometimes severely erode and steepen the beach. Sand usually returns during the summer months (39). Storm waves in the winter of 1968-69 caused the most severe incidence of beach erosion in modern times. The vegetation line on the backbeach has receded about 30 feet over the last 20 years (232). The tsunami of 1957 reached a height of 18 feet (5 m) above sea level at Ma'ili Beach (20;329).

OFF LUALUALEI BEACH PARK

The bottom offshore of much of Lualualei Beach Park consists of low relief limestone formations separated by sand pockets of various sizes. The larger sand patches occur off the center of the beach in the vicinity of a sewer outfall. Consolidated limestone predominates between -20 and -40 feet (-6 to -12 m). The proportion of sand bottom increases with depth and sand covers almost half the bottom at -60 feet (-18 m). At -80 feet (-24 m), the bottom is entirely sand (165;OCRI-62T1).

OFF MA'ILI BEACH

As off the Lualualei section to the north, the bottom off Ma'ili Beach reaches a depth of 12 feet (4 m) not far from shore, then deepens gradually offshore. Near shore the limestone bottom is interrupted by sand channels, including a large channel which comes in to shore south of the jetty at Ma'ili'ili Stream. At depths over -25 feet (-8 m) there is little or no sand. The bottom generally lacks relief except for the drop to the sand channel that meets Ma'ili Beach. Two major drop-offs, one from -50 to -60 feet (-15 to -18 m) and the other from -85 to -120 feet (-26 to -37 m), occur offshore (126;OCRI-62T2).

WAI'ANAE ARTIFICIAL "REEF"

In order to create an artificial "reef" habitat on an otherwise featureless bottom, concrete sewer pipes and old car bodies were dumped in deep water one mile south of Poka'i Bay (MAP 61) beginning in 1964 (98;126). The artificial habitat is scattered over an area of around 25 acres (10 ha) between -45 and -95 feet (-14 to -29 m). Heavy winter swells cause the pipes to shift position and collisions between pipes have reduced many to rubble (126;371). The natural bottom in the area of the artificial substrata is smooth limestone and sand with little relief (165).

FLORA AND FAUNA

OFF LUALUALEI BEACH PARK

Coral cover is sparse off most of Lualualei Beach Park. Coral cover off the old Mikilua Beach Park (northern section of Lualualei Beach Park) is around 17% at a depth of 10 feet (3 to 4 m) and 30% at a depth of 40 feet (12 m). Ten species of coral are represented in shallow water and 15 species occur offshore, making this one of the more diverse coral communities off the coast between Makaha (MAP 60) and Ma'ili Point (MAP 63). Porites lobata is by far the most abundant species. Montipora verrucosa is common at -10 feet, uncommon at -40 feet. Pocillopora meandrina ranks second in abundance offshore. An uncommon coral, Porites pukoensis, is reported from -40 feet offshore (156;OCRI-62B1).

Off the middle of Lualualei Beach Park and in the general vicinity of a sewer-pipe alignment coral cover is only around 6 to 8 % at -10 feet (-3 to -4 m), 3 to 12 % at -40 feet (-12 m), and 1% at -60 feet (-18 m)(156;165). However, at a station in shallow water along the outfall alignment, one survey recorded 30% coral cover (nearly all *Porites lobata*)(156). The dominant coral species at all depths is *Porites lobata* (156;165;OCRI-62T1). Many dead heads of *Pocillopora meandrina* occur off this section of coast (165).

Fleshy algae are sparse throughout most of the nearshore bottom, although a mat of closely-cropped species is present on hard substrata (165). The brown alga, *Dictyopteris australis*, is reported as prominent at a depth of approximately 30 feet off the Mikilua Beach section (OCRI-62B1). Fleshy algae (mostly *Sargassum* sp.) cover 11% of the bottom at a depth of 40 feet near the outfall diffuser. Coralline algae cover 5% of the bottom at -60 feet (-18 m) off the sewer outfall. Elsewhere, cover by coralline algae is reported at 1% or less off the Beach Park (165).

Sea urchins are conspicuous, especially *Tripneustes gratilla*, with densities exceeding one per square meter in shallow water. Other species present are *Echinometra mathaei*, *Echinothrix diadema*, *E. paucispinum*, *Echinostrephus aciculatus*, and *Heterocentrotus mammillatus* (156;165;OCRI-62B1,T1). *Echinostrephus* is most common in deeper water (156). The octocoral, *Anthelia edmondsoni*, occurs throughout the northern area (156).

Fishes are not particularly abundant in the waters off Lualualei Beach Park (OCRI-62T1). The fauna around ledges on the limestone bottom off the northern end of the Beach Park is moderately diverse. At least forty-nine species are recorded from a depth of 10 feet (3 to 4 m) and at least 57 species occur at a depth of 40 feet (12 m)(156). A survey in the general vicinity of the latter station found 49 species, of which fourteen are common. Among these are *Stethojelis balteata*, *Sufflamen bursa*, *Thalassoma duperreyi*, *Cirrhitops fasciatus*, *Coris gaimardi*, *Chaetodon miliaris*, *Canthigaster coronata*, *Halichoeres ornatissimus*, *Anampses chrysocephalus*, *Parupeneus multifasciatus*, and *Acanthurus nigrofuscus*. Less common, but of special interest, are the cleaner wrasse, *Labroides phthirophagus*, the boxfish, *Ostracion meleagris*, and the deep water species, *Chaetodon kleini* (OCRI-62F1).

Surveys of fishes off the middle of the Park have noted up to 40 species in shallow water (depths of approximately 10 feet or 3 to 4 m) and as many as 70 species at depths of 40 ft (12 m). *Pervagor spilosoma* and *Thalassoma duperreyi* are most abundant inshore; *P. spilosoma*, *Naso hexacanthus*, *Dascyllus albisella*, *Adioryx xantherythrus*, *Chaetodon miliaris*, and *Chromis verator* are most common offshore (156). The assemblage along the sewer outfall alignment is heavily dominated by the filefish, *Pervagor spilosoma* (165). *Melichthys vidua*, *Thalassoma duperreyi*, *Chromis verator*, *Abudefduf abdominalis* (OCRI-62T1), and *Acanthurus olivaceus* are common offshore (165).

OFF MA'ILI BEACH

Coral cover does not exceed 2% of the bottom in shallow water (-10 to -15 feet or -3 to -5 m) off Ma'ili Beach (OCRI-62T2). Coral cover is reported as 24% at -20 feet (-6 m), 7% at -40 feet (-12 m), and 10% at -60 feet (165). On the smooth limestone and sand bottom surrounding the artificial "reef" at depths below 80 feet (24 m) corals cover no more than 2% (116;126;165) or less (371) of the bottom. Porites lobata is the dominant species at all depths, followed in abundance by Pocillopora meandrina (126;165). The sea urchins, Echinometra mathaei and Echinothrix calamaris, are abundant in shallow water and to -40 feet (-12 m)(165). The sea urchin, Tripneustes gratilla, is common at -50 feet (-15 m)(OCRI-62T2).

Algal cover is estimated at 15% in water 10 to 15 feet (3 to 5 m) deep nearshore. Nine species of algae are noted. Asparagopsis taxiformis is the most abundant, followed by Laurencia sp., Halimeda discoidea, and Ulva reticulada (OCRI-62T2). Much of the limestone bottom offshore to -100 feet (-30 m) is carpeted by a mat of closely cropped algae (165). Principal forms in the mat are Amansia, Symploca, Herposiphonia, Dictyota, Dictyosphaeria, Caulerpa, and Schizothrix (116; also Wai'anae Artificial "Reef"). Cover by coralline algae (principally Hydrolithon breviclavium) is around 30% at depths of 40 to 90 feet (12 to 27 m; 116; 126).

The fish fauna at depths between 20 and 60 feet (6 to 18 m) is more diverse and fishes are more abundant than elsewhere along the Wai'anae coast. Thirty-six species are recorded. Pervagor spilosoma heavily dominated the assemblage in 1975. Other abundant species are Chaetodon miliaris, Chromis verator, Plectroglyphidodon imparipennis, and Myripristis sp. (165). More recent observations noted as common the surgeonfishes, Acanthurus nigroris and A. triostegus, and the wrasse, Thalassoma duperreyi (OCRI-62T2).

WAI'ANAE ARTIFICIAL "REEF"

Oysters (Ostrea hanleyana), bryozoans (Phidelopora sp.), and tunicates (Didemnum candidum) predominate on the inner surfaces of concrete pipes of the artificial "reef" at depths of 45 to 95 feet (14 to 29 m) off Ma'ili. Vermetids (Dendropoma platypus), limpets (Hipponix pilosus), and corals (Pocillopora meandrina and Porites lobata) are conspicuous attached organisms on the outer surfaces. Fishes selectively graze the algal growth, leaving mostly blue-greens (such as Schizothrix calcicola and Lyngbya majuscula) (126).

At least 167 species of fish are recorded from around the artificial substrata. Consistently most abundant are Acanthurus olivaceus, Mulloidichthys flavolineatus, Naso hexacanthus, Myripristis berndti, Parupeneus multifasciatus, Chromis verator, and Dascyllus albisella (98;126;198). A sunken barge has attracted at least 39 species of fish, including large schools of Decapterus *macarellus*, *M. vanicolensis*, *Naso hexacanthus*, *Acanthurus olivaceus*, *Aprion virescens*, and *Scarus perspicillatus* (198).

WATER QUALITY

NEARSHORE WATERS

Coastal waters are classified "A" in Department of Health water quality regulations (189). Some houselots behind the shoreline are served by cesspools, although portions of Ma'ili are connected into the Wai'anae sewage treatment system (186). Several injection wells are utilized as well for sewage disposal (219). The outfall for the Wai'anae STP is located 3000 feet (915 m) offshore of Lualualai Beach Park in 34 feet (10 m) of water. The discharge rate is approximately 1.72 mgd of primary treated domestic sewage. High concentrations of bacteria of fecal origin are present in the zone of mixing. Planning is underway to add secondary treatment and to increase the total length of the outfall to 6000 feet. The discharge would then be at a depth of 150 feet (46 m) (156).

Underwater visibility is about 60 feet fronting Lualualei Beach Park. Directly off Ma'ili Beach Park, underwater visibility is only 25 or 30 feet (OCRI). Visibility of 80 feet or better is reported in offshore waters (236;OCRI).

MA'ILI'ILI STREAM

Ma'ili'ili Stream flows only after heavy rains, but at these times, sediment plumes may enter the ocean and discolor nearshore waters for a day or more. Ma'ili'ili Stream is given an ecological quality rating of III: moderate to low natural and/or water quality (well exploited, modified, or degraded) (223).

USES

LUALUALEI BEACH PARK

Lualualei Beach Park includes the former Mikilua Beach Park and extends along the coast from Poka'i Bay Beach Park (MAP 61) to the mouth of Ma'ili'ili Stream. Beachrock creates problems of access to the water along much of the shoreline. Waves and currents become dangerous when winter swells approach Hawai'i from the North Pacific. The park is, however, popular with beach campers and pole fishermen (39). Throw-netting occurs off rocky sections of the coast. Board and body surfing occurs offshore of the sewage treatment plant.

Fishing is moderate to heavy along the coast from Lualualei Beach Park to the south end of Ma'ili Beach Park. Pole fishing and spearfishing are the most intensive activities. The jetty south of Kalaeokakao Point is a focus for pole fishermen, but the entire shoreline is fished.

MA'ILI BEACH PARK

Ma'ili Beach Park includes the former Ma'ili'ili Beach Park and extends along the coast from the mouth of Ma'ili'ili Stream to Ulehawa Beach Park (MAP 63). Waters are generally calm in the summer. The most popular swimming area is off the wide sand beach near Ma'ili'ili Stream. Deep waters are reached close to shore. Winter swells create strong backwashes and powerful rip currents in nearshore waters all along the beach (39). Throw-netting occurs off rocky shore areas. This coast is visited extensively by public school classes on marine education field trips.

Construction of a jetty to keep sand from barring the mouth of Ma'ili'ili Stream intruded on a once popular surfing spot (39). Board surfing is no longer possible at this site, although body surfing and belly-board (paipo) surfing remains good (86). Off the center of the beach is a body surfing site.

OFF MA'ILI - WAI'ANAE ARTIFICIAL REEF

The concrete pipes and old car bodies dumped to create habitats for marine organisms abound with fishes that are an attraction to sport divers. Lobsters (Panulirus sp.) are abundant. Anglers in boats drift over the artificial "reef" and hook goatfishes (126). Trapping and ornamental fish collecting are important activities in deep waters offshore. The Wai'anae Artificial Reef has been extensively studied to determine the advantages and disadvantages of enhancing fish productivity by dumping various items in areas characterized by low bottom relief and low abundance of fishes.

STUDIES AND SURVEYS

16 - Bathen (1978): p. 63, figs. 15,26. Compilation and analysis of offshore water circulation data. Additional references.

25 - Campbell (1972): p. 11, tables 3,4. Width and sand volume for Ma'ili Beach (as "Maile") measured several times in 1962/63 and 1971/72.

98 - Kanayama and Onizuka (1973): Survey of fishes around artificial "reefs" off O'ahu; Wai'anae site off Ma'ili.

116 - Littler (1971): p. 26-35, 41, figs. 1, 5, tables III-VIII. Study and survey of crustose coralline algae off Ma'ili (vicinity of Wai'anae artificial "reef") and Waikiki. Variation in bottom cover, density, and frequency of several species.

126 - McVey (1970): Ecology of fishes attracted to enhanced substratum relief of an artificial "reef" off Ma'ili. Table IV. Summary of fish abundance and number of species at 5 of nine sites (-50 to -85 feet deep) between Wai'anae

(MAP 61) and Maipalaoa Beach Park (MAP 63). Extensive species list of algae, invertebrates, and fishes on and around concrete pipes and natural substrata nearby. Fish grazing studies. Plankton and physico-chemical factors sampled in water column.

147 - Moberly and Chamberlain (1964): p. 68-9, fig. 50. Sand sorting and composition of the north end of Ma'ili Beach. Beach and offshore profile. Seasonal changes in beach sand volume and width, 1962-63.

156 - Oceanic Institute (1976): app. B. Sta. 5,6,7 of seven off the Wai'anae coast at which physical, chemical, plankton, and bacteria surveis were conducted in Summer 1974. Sta. 4,5,6 of six at which fishes, corals, and benthic invertebrates were surveyed in August 1974. Samples 20-31,56-59,82,83 of ninety sediment samples collected along Wai'anae coast analyzed for grain size distribution.

157 - Oishi (1973): Survey of fishes around Wai'anae artificial "reef".

165 - Reed, Kay, and Russo (1977): Transects C and D of five off Wai'anae coast. Substratum types, algae, coral, fishes, macroinvertebrates, and micromolluscs surveyed at five depths along each transect line.

198 - DIVF&G (1974): Fish survey at the Wai'anae offshore artificial "reef" located off Ma'ili.

371 - Auyong, et al. (1975): Studies on corals, algae, and fishes (including gut contents analysis) on and around both artificial and natural substrata at the Wai'anae artificial "reef" off Ma'ili. Some physico-chemical parameters measured.

500 - Whang (1981): Study of Ma'ili Beach width spanning a 30 year period (1949-59, 1965-71, 1975-79) using aerial photographs to assess beach stability. Fig. IV-4, Table IV-4.

MAP 63 - MA'ILI POINT

(MA'ILI, MAIPALAOA STREAM, MA'ILI BEACH PARK, MAIPALAOA BEACH, MA'ILI POINT, ULEHAWA BEACH PARK, PU'U O HULU BEACH)

- Waianae Quadrangle
- POD, 1:6000 BW, 1:

PHYSIOGRAPHY

LUALUALEI VALLEY - MA'ILI

The residential area of Ma'ili stretches along the coast between Pu'u Ma'ili'ili (MAP 62) and Pu'u o Hulu Kai (MAP 64). These are mostly homestead lands. (Also MAP 62). Maipalaoa Stream drains a relatively small area of Lualualei Valley north of Pu'u o Hulu Kai. This stream flows only following periods of heavy rainfall.

MA'ILI BEACH

Ma'ili Beach extends south from the mouth of Ma'ili'ili Stream (MAP 62) to near the mouth of Maipalaoa Stream. The backshore is composed of old beach ridges and inactive dunes (146). Offshore of Ma'ili Beach, the bottom deepens sufficiently to allow high waves to break on shore, causing large seasonal and year-to-year shifts in beach sand (500). Surveys in 1962-63 indicate that northern Ma'ili Beach has a seasonal variation of about 75 feet. During the winter, the foreshore slope is relatively steep, whereas in the summer, it is flat (147). The middle section of Ma'ili Beach has grown but the two ends of the beach have experienced chronic erosion over a long-term period. Ercsion of a 2,500 foot length of north Ma'ili Beach appears to be continuous. During the 1949 to 1979 period, the vegetation line receded by as much as 72 feet. The major erosion was concentrated during the 1949-1959, 1965-1971, and 1975-1979 intervals. The middle section of Ma'ili Beach accreted between 1949 and 1979. The vegetation line advanced seaward by as much as 99 feet in this period. The source of sand is possibly from the eroding ends of the beach (500).

At the southern end of Ma'ili Beach, the vegetation line receded 32 feet over a 30-year period. Shoreline retreat appears to be continuous over time and may eventually cause residential areas along the backshore to become susceptible to winter storm waves (500).

Erosion in the winter of 1968-69 was particularly severe (232). This coast is subject to storm wave and tsunami flooding. Runup from the 1946 tsunami reached 16 feet (5 m) above sea level at Maipalaoa Beach (329).

MA'ILI POINT - PU'U O HULU SHORELINE

A spur of the Wai'anae Range known as Pu'u o Hulu forms Ma'ili Point, one of two prominent points along the Wai'anae Coast. A long coastline of raised reef curves around Ma'ili Point. The raised reef is attributed to the +25 foot stand (Waimanalo) of the sea estimated as occurring roughly 40,000 years ago (128;211). A low cliff extends along the entire shore from Maipalaoa Stream to Ulehawa Stream (MAP 64)(39).

OFF MA'ILI BEACH

Smooth limestone broken by small depressions containing sand is the predominant bottom type in waters between -10 and -20 feet (-4 to -6 m) off Ma'ili Beach. Little sand is present on the limestone bottom between -40 and -60 feet (-12 to -18 m) (165;OCRI-63T1). The proportion of sand bottom is greater below -80 feet (-24 m)(165).

OFF MAIPALAOA BEACH AND MA'ILI POINT

Old reef limestone extends seaward off Ma'ili Point as a submerged shelf interrupted by surge channels with sand bottoms (OCRI). A cove off Maipalaoa Beach is protected by the shallow, offshore reef and has a bottom of sand and scattered limestone outcrops (39).

FLORA AND FAUNA

OFF MAIPALAOA BEACH AND MA'ILI POINT

Corals reach a maximum bottom cover of 13% at a depth of 40 feet (12 m) offshore of Maipalaoa Beach Park. In shallow water (-20 feet or -6 m), only five percent of the bottom is covered by live coral. Coral cover is 8% at a depth of 60 feet (18 m) and corals contribute no more than one percent cover at depths of 80 and 100 feet (24 and 30 m)(165). Pocillopora meandrina and Porites lobata (growing as massive coral heads) are nearly equal in abundance at -20 feet and Poc. meandrina is dominant at -40 to -60 feet. Leptastrea purpurea is fairly common in patches throughout the area. Dead and pale heads of Poc. meandrina are common (165;OCRI-63B1).

Fleshy algae (mostly Sargassum sp.) are abundant in deep water offshore. Algal cover is 13% at -80 feet (-24 m), increasing to 20% at -100 feet (30 m). Coralline algae cover 4% of the bottom at -80 feet and 8% of the bottom at -100 feet (-30 m) (165).

The pincushion star, Culcita novaeguineae, is fairly abundant, and a variety of other echinoderms (including Heterocentrotus mammillatus, Acanthaster planci, Diadema paucispinum, Echinothrix diadema, Echinostrephus aciculatus, and Holothuria cf. pervicax) occur in low abundance offshore (OCRI-63B1). Echinometra mathaei and Echinothrix calamaris are the only echinoderms reported in one survey (165).

Juvenile fishes are present near shore. Large schools of Acanthurus olivaceus and A. triostegus occur in waters less than 20 feet deep (OCRI-63T1). A fairly diverse fish assemblage is found in deeper water (-50 ft or -15 m) off Ma'ili Point. Sixty-three species are recorded, of which 21 are rated common. Among the most common are Dascyllus albisella, Zebrasoma flavescens, Chaetodon miliaris, C. multicinctus, C. kleini, Thalassoma duperreyi, Forcipiger flavissimus, Acanthurus olivaceus, Ctenochaetus strigosus, Chromis verator, Anthias thompsoni, and Bodianus bilunulatus. Heniochus diphreutes and Chromis hanui are especially abundant (OCRI-63F1). A survey in the same general area recorded 24 species of fishes from depths ranging between 20 and 100 feet (6 to 30 m). Pervagor spilosoma predominated in 1975 (165).

WAI'ANAE ARTIFICIAL "REEF"

The variety and abundance of fishes associated with old pipes, cars, and barge sections dumped offshore of Ma'ili Beach as an "artificial reef" are much higher than found over the surrounding limestone bottom (98;126;198). Some of the more commonly encountered species are Mulloidichthys vanicolensis, M. flavolineatus, Parupeneus multifasciatus, Chromis verator, Myripristis sp., Decapterus macarellus, Aprion virescens, and Scarus perspicillatus (126). (Also MAP 62).

WATER QUALITY

NEARSHORE WATERS

Coastal waters are rated "A" in Department of Health water quality regulations (189). Cesspools are used for sewage disposal in coastal communities. A small volume of domestic sewage (0.2 mgd) is discharged into coastal waters south of Ma'ili Beach Park from the Naval ammunition depot at Lualualei (186).

Although Maipalaoa Stream flows only a few times a year after heavy rains, plumes of stream-borne sediment may enter the ocean and discolor nearshore waters for a day or longer. The waters surrounding Ma'ili Point are within one of five areas off O'ahu designated as major post-storm red water areas by the Department of Health (306). This particular area extends from Kepuhi Point (MAP 59) southeast to Kahe Point (MAP 66). Underwater visibility is limited to about 20 feet near shore but improves to 50 feet in water over 40 feet deep (OCRI).

USES

MA'ILI BEACH PARK

The opportunities and limitations for uses along the southern-most section of Ma'ili Beach Park are the same as for the northern portion (see MAP 62). Beaches and old beach ridges were formerly exploited as a commercial source of sand at Ma'ili (146). Body surfing is practiced off the beach at the south end of the Park.

ULEHAWA BEACH PARK - MAIPALAOA BEACH

The sand and limestone shoreline south of Maipalaoa Stream to Ma'ili Point was formerly called Maipalaoa Beach Park, but has been combined with Ulehawa Beach Park. A shallow cove is formed by a reef shelf in front of Maipalaoa Beach. This cove is protected from dangerous currents even during periods of high surf and is one of the safer areas for swimming along the Wai'anae coast (39).

The surf break offshore of Maipalaoa Beach Park is excellent for board and paipo board surfing during the summer. The strong currents generated by large surf, the shallow reef shelf, and occasional shark sightings are potential hazards (39;86).

ULEHAWA BEACH PARK - PU'U O HULU BEACH

The raised reef shoreline around Ma'ili Point is an undeveloped park (formerly called Pu'u o Hulu) now combined with Maipalaoa and Ulehawa Parks into Ulehawa Beach Park. The surf pounds this shoreline almost continually and is especially hazardous in winter months. Pole fishermen are the principal users of the park (39).

OFF MA'ILI POINT

The coast from the south end of Ma'ili Beach Park and around Ma'ili Point receives moderate to heavy fishing use, largely by pole and spear fishermen seeking papio, ulua, goatfish, and surgeonfish off the shoreline. Some net fishing and throw-netting is practiced off the rocky coast of Ma'ili Point. Trapping and ornamental fish collecting are the most important offshore fisheries.

Summer waves provide good board and paipo board surfing at two sites off Ma'ili Point. The shallow bottom and sharks are hazards reported by surfers (86). Divers frequent the waters offshore of Ma'ili Point, presumably attracted by a diverse fish assemblage and caves eroded in a submarine cliff. Commercial dive shops run charters to these caves. Currents are reported as unpredictable and sometimes strong around Ma'ili Point (236).

STUDIES AND SURVEYS

16 - Bathen (1978): p. 63-64, figs. 15,26. Compilation and analysis of offshore water circulation data. Additional references.

98 - Kanayama and Onizuka (1973): Survey of fishes around artificial "reefs" off O'ahu; Wai'anae site off Ma'ili.

116 - Littler (1971): p. 26-35, 41, figs. 1, 5, tables III-VIII. Study and survey of crustose coralline algae off Ma'ili (vicinity of Wai'anae artificial "reef") and Waikiki. Variation in bottom cover, density, and frequency of several species.

126 - McVey (1970): Ecology of fishes attracted to enhanced substratum relief of an artificial "reef" off Ma'ili. Table IV. Summary of fish abundance and number of species at 5 of nine sites (-50 to -85 feet deep) between Wai'anae (MAP 61) and Maipalaoa Beach Park (MAP 63). Extensive species list of algae, invertebrates, and fishes on and around concrete pipes and natural substrata nearby. Fish grazing studies. Plankton and physico-chemical factors sampled in water column.

156 - Oceanic Institute (1976): app. B. Samples 58-61,81 of ninety sediment samples collected along Wai'anae coast analyzed for grain size distribution.

157 - Oishi (1973): Survey of fishes around Wai'anae artificial "reef".

165 - Reed, Kay, and Russo (1977): Transect E of five off Wai'anae coast. Substratum types, algae, coral, fishes, macroinvertebrates, and micromolluscs surveyed at five depths along each transect line.

168 - Richmond and Mueller-Dombois (1972): p. 386, fig.s 2.11A, 2.11B, table 1. Transects 11A and 11B of twenty-three around O'ahu in study of coastal plant assemblages.

198 - DIV F&G (1974): Fish survey at the Wai'anae offshore artificial "reef" located off Ma'ili.

371 - Auyong, et al. (1975): Studies on corals, algae, and fishes (including gut contents analysis) on and around both artificial and natural substrata at the Wai'anae artificial "reef" off Ma'ili. Some physico-chemical parameters measured.

500 - Whang (1981): Study of Ma'ili Beach width spanning a 30 year period (1949-59, 1965-71, 1975-79) using aerial photographs to assess beach stability. Fig. IV-4, Table IV-4.

MAP 64 - PU'U O HULU

(MA'ILI POINT, PU'U O HULU BEACH, ULEHAWA BEACH PARK, ULEHAWA STREAM)

- Waianae Quadrangle
- POD, !:6000 BW, 1:

PHYSIOGRAPHY

MA'ILI POINT

Ma'ili Point is one of two prominent projections along the Wai'anae coast. The Point occurs at an isolated spur from the Wai'anae Range called Pu'u o Hulu.

NANAKULI - ULEHAWA STREAM

The residential area (homestead lands) of Nanikuli lies south of Pu'u o Hulu across a portion of Lualualei Valley drained by Ulehawa Stream. (Also MAP 62). Ulehawa Stream flows only infrequently following periods of heavy rainfall.

PU'U O HULU COAST

The entire shoreline of Pu'u o Hulu Beach extending from Ma'ili Point to Ulehawa Beach is a low cliff fronting a raised reef platform (also MAP 63).

ULEHAWA BEACH

A pocket beach (substantially narrowed by winter surf) occurs near the mouth of Ulehawa Stream. However, the rest of Ulehawa Beach north and south of the pocket beach is a narrow, steep, sandy shore having alternating sections of sand and beach rock edged by extensive outcrops of beachrock. Over a 30-year period, the beach has generally been stable, with some evidence of localized accretion (500). The coastline is subject to storm wave and tsunami flooding (88). The 1946 tsunami caused runup to an elevation of 19 feet (6 m) south of Ulehawa Stream mouth (329).

OFF ULEHAWA BEACH

A narrow, submerged shelf of pitted limestone lies off Ulehawa Beach Park. From the seaward edge of this shelf (at a depth of about 12 feet or 4 m) the bottom drops away into deeper water as smooth limestone veneered with sand. A sand-bottom channel crosses the limestone and comes in to shore at the mouth of Ulehawa Stream (OCRI-64B1).

FLORA AND FAUNA

OFF ULEHAWA BEACH

The submerged limestone shelf off Ulehawa Beach is heavily populated by the sea urchin, *Echinometra mathaei*. Coral and algal cover are sparse. Coral cover increases to 20 or 30% on the flat limestone at a depth of 25 feet (8 m). *Porites lobata* (occurring as large heads) and *Pocillopora meandrina* are most common, although a *Montipora* sp. is also common. The sea urchin, *Tripneustes gratilla*, is abundant here. Ten species of fish are recorded from depths of 6 to 40 feet (2 to 12 m). Fish abundance increases with depth. Most common are *Naso hexacanthus*, *Chaetodon miliaris*, *Dascyllus albisella*, and *Melichthys vidua* (OCRI-64B1).

WATER QUALITY

NEARSHORE WATERS

Department of Health water quality regulations classify these coastal waters as "A" (189). Underwater visibility is limited to around 20 feet in the shallow waters fronting Ulehawa Beach Park, but improves to 40 or 50 feet farther offshore (OCRI).

ULEHAWA STREAM

Although Ulehawa Stream flows only a few days to a few weeks a year, plumes of fine sediment can be discharged after heavy rains and discolor nearshore waters for a day or more. Ulehawa Stream is given an ecological rating of III: moderate to low natural and/or water quality (well exploited, modified, or degraded)(223).

USES

ULEHAWA BEACH PARK - PU'U O HULU BEACH

Ulehawa Beach Park now includes the former Maipalaoa (MAP 63) and Pu'u o Hulu Beach Parks. Entry and exit from the raised reef shoreline of the Pu'u o Hulu Beach section is dangerous, especially in the winter months, because of the constant shorebreak. This section of coast is mostly frequented by pole fishermen (39). Limu is frequently collected off this section of Ulehawa Beach Park.

ULEHAWA BEACH PARK - ULEHAWA BEACH

Ulehawa Beach is the most utilized section of the long, shoreline park extending from the mouth of Maipalaoa Stream (MAP 63) to Nanakuli Beach Park (MAP 65). Except where the beach slopes into a sand channel off Ulehawa Stream, the sand shoreline meets beachrock or jagged reef rock at the waterline. Deep water occurs close to shore except in front of Ulehawa Stream. Inshore waters are relatively calm and safe for swimming in the summer months. When heavy surf conditions occur in the winter months, powerful rip currents develop and, combined with the large shorebreak, make swimming dangerous (39). Longshore currents moving towards the northwest are moderate under small surf conditions. This section of coast receives moderate fishing use by pole fishermen and spear fishermen, the latter entering the water from sandy sections of the shoreline. Net fishing occurs here.

OFF ULEHAWA BEACH PARK

The constant shorebreak along Ulehawa Beach Park offers good belly-board and body surfing, especially in the winter months (39;86). Ornamental fish collecting is a major fishery offshore.

STUDIES AND SURVEYS

16 - Bathen (1978): p. 65, figs. 15,26. Compilation and analysis of offshore water circulation data. Additional references.

500 - Whang (1981): Study of Ma'ili Beach width spanning a 30-year period (1949-59, 1965-71, 1975-79) using aerial photographs to assess beach stability. Fig. IV-4, Table IV-4.

MAP 65 - NANAKULI

(NANAKULI, NANAKULI STREAM, NANAIKAPONO STREAM, ULEHAWA BEACH PARK, NANAKULI BEACH PARK, PILI O KAHE)

- Waianae Quadrangle
- Schofield Barracks Quadrangle
- Ewa Quadrangle
- POD, 1:6000 BW, 1:

PHYSIOGRAPHY

ULEHAWA BEACH

The shoreline fronting the Ulehawa section of Lualualei Valley is a seasonally wide sand beach which extends south from near the mouth of Ulehawa Stream (MAP 64) to a rocky headland near the mouth of intermittent Nanaikapono Stream. Winter storm waves significantly cut back and steepen the beach profile. The coast is subject to storm wave and tsunami flooding (88). Runup from the 1946 tsunami reached 20 feet (6 m) above sea level at Nanakuli (20;329).

NANAKULI BEACH

Nanakuli Beach (also known as Kalaniana'ole Beach) is a pocket beach 500 feet (150 m) long and 125 feet (40 m) wide situated between two points of raised reef. Nanakuli Stream meets the beach at its southern end (which is sometimes called Zablan's Beach), but the stream mouth is usually blocked by sand. The beach front is quite steep (147). Nanakuli beach experiences seasonal variations in width of as much as 50 feet (15 m). The southern end accretes in the winter and erodes back in the summer (334). The southern section of the beach appears to have a 26-year history of accretion (500). The northern beach has the opposite seasonal pattern. Nanakuli Beach remained relatively stable during the January 1980 storm that severely eroded other leeward O'ahu beaches (501).

PILI O KAHE BEACH

The southern portion of Nanakuli Beach Park, formerly called Pili o Kahe Beach Park, is situated on a low point of raised reef. (Also MAP 66).

OFF ULEHAWA AND NANAKULI BEACHES

Seaward of Ulehawa and Nanakuli Beaches there is a low relief limestone bottom with a sand veneer. A large sand channel crosses the limestone bottom just north of the point occupied by Nanaikapono Elementary School and merges with Ulehawa Beach in the vicinity of an unnamed stream mouth. An even larger sand channel cuts through the limestone bottom seaward of the mouth of Nanakuli Stream. The drop-off to deep water is fairly abrupt off of Ulehawa Beach, but is more gradual in front of Kalaniana'ole Beach Park (OCRI-65T1).

FLORA AND FAUNA

OFF ULEHAWA BEACH

The limestone bottom some 300 to 400 feet (90 to 120 m) seaward of Ulehawa Beach supports a sparse (2% cover) growth of the coral, *Porites*. Live coral covers 5% of the bottom 30 feet off the mouth of Nanaikapono Stream and 14% of the bottom 300 feet seaward. *Porites*, *Montipora*, and *Pocillopora* are present (383;OCRI-65T1).

NANAKULI SOLUTION BENCH

An algal turf on the solution bench north of Nanakuli (Kalaniana'ole) Beach is dominated by *Valonia aegagropila*. *Jania capillacea*, *Sargassum* sp., and *Padina* sp. are common (110).

OFF NANAKULI (KALANIANA'OLE) BEACH

The low relief limestone fronting Ulehawa and Nanakuli Beaches has a rather barren appearance. Coral cover (mostly *Pocillopora meandrina*) does not exceed 5% of the bottom (OCRI-65T1). Twenty feet off Nanakuli Stream, coral cover is nearly 20% in an area of high relief. *Porites* and *Pocillopora* are most common. Fishes and sea urchins are abundant. Farther offshore the bottom is barren (383).

WATER QUALITY

NEARSHORE WATERS

Coastal waters are class "A" in Department of Health water quality regulations (189). Beachside homes have cesspools. Prior to 1978 the DOH conducted monthly microbiological monitoring of waters off Nanakuli Beach Park. Mean concentrations of total and fecal coliform bacteria never exceeded DOH or EPA designated maximum levels for recreational waters (188). Underwater visibility off Nanakuli Beach is 25 to 30 feet (OCRI), but improves offshore (139).

NANAKULI STREAM

Although barred by the beach most of the year, Nanakuli Stream breaches the sand and empties into the ocean following heavy rains. For a day or more after high discharges, nearshore waters may be discolored by suspended sediments. The upper reach of Nanakuli Stream is given an ecological quality rating of II: moderate to high quality water or natural values (223).

USES

ULEHAWA BEACH PARK

Ulehawa Beach Park encompasses the former Maipalaoa (MAP 63), Pu'uohulu (MAP 64), and Ulehawa Beach Parks extending from Ma'ili Beach Park (MAP 63) to Nanakuli Beach Park. Only the Ulehawa portion is developed. The wide sand beach centered around the comfort station is the most popular section of Ulehawa Beach Park. (Also MAP 64). Elsewhere the beach is narrow, steep, and edged by extensive beachrock outcrops that interfere with access to the water (39). Strong longshore currents sometimes occur off the beach. The shorebreak provides good body and belly-board surfing (86). Sand from this area was exploited at one time for commercial purposes (146).

The southern section of Ulehawa Beach Park and Kalaniana'ole Beach (Nanakuli Beach Park) receive moderate fishing pressure from pole fishermen seeking ulua, papio, 'o'io, and goatfish.

NANAKULI BEACH PARK - KALANIANA'OLE BEACH

Nanakuli Beach Park extends southeast along the coast from Ulehawa Beach Park and encompasses the former Kalaniana'ole Beach Park and Piliokahe Beach Park (see MAP 66). A wide pocket beach in the Kalaniana'ole Beach section offers camping and swimming. High surf conditions, especially in the winter months, produce a large shorebreak on the steep face of the beach and strong rip currents near shore. At such times these waters become very dangerous. The section of beach in front of Nanakuli Stream is known as Zablan Beach and is considered the safest part of the Beach Park (39). Body surfing is occasionally good in the winter at several sites off Kalaniana'ole Beach. Surfers report occasional shark sightings (86). Novice SCUBA divers frequently follow the large sand channel fronting Zablan Beach to deeper water offshore (39). Beach sand was formerly exploited for construction purposes at Nanakuli (146).

OFF ULEHAWA AND NANAKULI BEACH PARKS

Zablan Beach and the adjacent sand channel are an entry/exit point for SCUBA divers. Commercial dive shops utilize these waters for both beginning and advanced SCUBA classes and dive charters. The major attractions for sport divers occur farther south along the coast (see MAP 66). Offshore waters are subject to tidal currents running alongshore that can be quite strong (OCRI).

Spearfishing occurs offshore but it is concentrated south of this section. Net fishing occurs in the large sand channel fronting Nanakuli (Zablan) Beach. Pole fishing from boats is common offshore and ornamental fish collecting is widespread off this coast.

STUDIES AND SURVEYS

16 - Bathen (1978): p. 65, figs. 15,26. Compilation and analysis of offshore water circulation data. Additional references.

25 - Campbell (1972): p. 11, tables 3,4. Width and sand volume for Nanakuli Beach measured several times in 1962-63 and 1971-72.

42 - R.M. Towill Corp. (1973 and later surveys; see MAP 66 for dates). App. A. Offshore sand depth and beach profiles (8 & 9 of nine between Kahe Point and Kalaniana'ole Beach). ((334) in Coles, Fukuda, and Lewis, 1981)

110 - Kohn (1959): Brief description of biota on solution bench at Nanakuli.

147 - Moberly and Chamberlain (1964): p. 68, fig. 49. Composition and sorting of Nanakuli Beach (Kalaniana'ole section) sand, and beach profile. Seasonal changes in beach sand volume and width, 1962-63.

168 - Richmond and Mueller-Dombois (1972): p. #87, fig. 2.10. Transect 10 of twenty-three and Study area 22. Study of coastal vegetation around O'ahu.

383 - Sea Engineering Services, Inc. (1975). Sites A,B,C of three in survey off Ulehawa and Nanakuli Beaches. Nearshore current and circulation observations; limited biological survey.

500 - Whang (1981): Study of Ma'ili Beach width spanning a 30-year period (1949-59, 1965-71, 1975-79) using aerial photographs to assess beach stability. Fig. IV-4, Table IV-4.

501 - Coles, Fukuda, and Lewis (1981): Summary of data collected relevant to the impact of the Kahe generating station on the marine environment. Description of the power station, temperature studies, beach and offshore sand profiles, benthic surveys of algae, corals, reef fishes, coral growth studies.

MAP 66 - KAHE

(NANAKULI BEACH PARK, PILI O KAHE, KAHE BEACH, HECO BEACH PARK, KAHE POINT)

- Ewa Quadrangle
- Schofield Barracks Quadrangle
- POD, 1:6000 BW, 1:

PHYSIOGRAPHY

PILI O KAHE BEACH

The southern section of Nanakuli Beach Park, formerly called Pili o Kahe Beach Park, is situated on a low promontory of raised reef. The only sand along the shoreline of the Pili o Kahe section is a 150-foot (45 m) long pocket beach ("Middle Beach") in a cove at the south end of the park. The beach is relatively stable and protected from north-west swell (39;334). This coast is subject to high surf and tsunami flooding (88).

KAHE BEACH

A wide sand beach known as Kahe Beach extends some 2,500 feet along the shore north of the HECO power station. The beach is bounded by rocky points to the north and a jetty to the south. Its width is 50 to 150 feet (30 to 45 m) and the face is generally quite steep. The beach is subject to large variations in width as seasonal changes in the wave regime cause sand to shift from one end of the beach to the other (334).

Kahe Beach has a history of chronic erosion (500). Over a 30-year period, the former sandy shoreline has been replaced by exposed rock and cobbles. Between 1949 and 1979, the shoreline retreated about 40 feet. Off the middle and southern sections of the beach are sand channels where seaward movement of sediment may occur (500). A severe Kona storm generated large waves on the southern and western shores of O'ahu during January 8-10, 1980. Storm damage to Kahe beach and reef environments produced the most dramatic alterations that have occurred since monitoring studies began in 1973 (334,501).

The Kona storm in January 1980 caused severe erosion of Kahe Beach and noticeable sand accretion in nearshore areas. A vertical scarp was eroded in the backshore, and the southern half of the seawall bordering Kahe Beach Park collapsed several months after the storm. Although some sections of the beach recovered to their normal volume after the storm, the average volume of sand on the entire beach was considerably less than the year before.

The January 1980 storm affected most of the beach. After that time, the area of erosion shifted, depending upon seasonal wave climate and littoral cycle (42).

Transfer of the Kahe Power Station effluent discharge offshore in 1976 appears to have altered the pattern of nearshore sand movement resulting in a loss of sand from the beach. About 55% of the sand transported into the Kahe cooling system is lost offshore by way of the outfall. The remainder is trapped in the intake basin, from which it is periodically dredged and trucked to the beach north of the basin and to temporary storage sites (501). A large volume of sand has accumulated off the outfall since commencement of offshore outfall operations in December 1976. Most of the deposit occurs within 150m of the outfall. Sand from Kahe Beach is transported south into the intake basin during the winter months. Sand trapped in the intake basin is removed from the seasonally reversing littoral cycle (501). Twenty foot high dunes which back the north (Manners Beach) end of the beach have resulted from HECO's practice of dumping sand dredged from the intake basin of the Kahe power facility (42). Runup from the 1946 and 1957 tsunamis reached 12 and 11 feet (4 m) respectively above sea level at Kahe Beach (329).

HECO POWER STATION

The Hawaiian Electric Company operates an oil-fired, power generating station north of Kahe Point, the largest power station on O'ahu. Two short boulder groins extend from shore to form a protective basin for the ocean water intake of the plant's cooling system. Heated water is dicharged into the ocean through a pipe to a depth of 27 feet (8 m) over sand bottom approximately 250 feet offshore (334). The discharge pipe extends off a small beach directly north of Kahe Point (324).

KAHE POINT

Kahe Point lies off a spur of the Wai'anae Range. The shoreline is a cliff 15 feet (5 m) high, cut in an emergent, solution-pitted reef. A small cove is located along the south side of the point (39;324).

OFF PILI O KAHE

Offshore of Pili o Kahe there is a low relief limestone bottom with sand channels and, in places, a sand veneer. A sand body extends south from the pocket beach at the south end of the beach park (137).

OFF KAHE BEACH AND HECO POWER PLANT

A large sand channel runs offshore at the HECO discharge pipe merging with an extensive body of sand offshore. Sand thicknesses in the nearshore deposits range from 3 to 15 feet (1 to 5 m) (137;351). Sand volume has increased since operation of the offshore outfall (334). North and south of the sand channel there are narrow, seaward sloping shelves with sand in pockets

(324). The shelves of limestone are of two distinct types: that to the north has low relief and is mostly covered by a veneer of sand. Sand pockets and small channels are interspersed (42;351;334;OCRI-66T1). Off Manners Beach the low relief shelf slopes offshore to a depth of about 40 - 50 feet (15 m) where there is a bottom of rubble and sand (OCRI-66B1). Off the power station, limestone bottom extends seaward between 200 and 300 feet (60 to 90 m) to a depth of around 35 feet (10 m)(324). All the reef areas are terminated seaward at various depths by an extensive sand body (501).The limestone shelf south of the sand channel is narrower and displays more relief in the form of depressions and limestone mounds (42;137).

FLORA AND FAUNA

OFF PILI O KAHE

The nearshore bottom is relatively barren off Pili o Kahe. Pocillopora meandrina is the principal coral, but cover does not exceed 5% of the bottom. The sea urchin, Diadema paucispinum, is common. Algae are present as low-growing mats on hard surfaces. Anthias thompsoni and Melichthys niger are most abundant and schools of Decapteris macarellus are common (OCRI-66T1).

OFF KAHE BEACH

Coral cover was formerly high in patches off the north end of Kahe (Manners) Beach (OCRI-66T1). Prior to January 1980 storm damage, cover ranged between 10 and 60 % of the bottom off Kahe Beach (334). Total cover is presently less than 10% (501). The principal species is Porites lobata (-9 m). Second in abundance is Pocillopora meandrina (501). The sea urchin, Tripneustes gratilla, is abundant around heads of P. lobata and P. compressa. Diadema paucispinum is abundant around heads of Pocillopora meandrina (OCRI-66T2).

A ledge at a depth of 50 feet (15 m) is dominated by Porites lobata, followed by Pocillopora meandrina. Coral cover approaches 40% of the bottom. Algae are present in a low-growing mat (OCRI-66B1). The steep drop-off below the ledge provides relief and large numbers of fishes are found there. The fish fauna is diverse, totaling at least 69 species. Twenty-two of these are common, with Chaetodon miliaris and Acanthurus thompsoni especially abundant. Among the more common species are Sufflamen bursa, Thalassoma duperreyi, Acanthurus dussumieri, Cirrhitops fasciatus, Chromis hanui, C. verator, Parupeneus multifasciatus, Pseudocheilinus octotaenia, Centropyge potteri, Ctenochaetus strigosus, Apogon sp., Melichthys vidua, Chaetodon klieni, Holacanthus arcuatus, and Acanthurus mata (OCRI- 66F1).

OFF HECO POWER PLANT - OFF KAHE POINT

Algal cover is highest in nearshore areas of high turbulence. Algal abundance increased slightly between 1979 and 1980, although diversity decreased.

Surveys of algae off Kahe have revealed 112 species, although algae are far less abundant in terms of bottom cover than corals. Red algal predominate. Most frequent are Lithothamnion spp., Jania capillacea, Oscillatoria spp., Gelidiella sp., Lyngbya sp., Symploca hydnoides, Peyssonelia rubra, Sphacelaria tribuloides, Dictyosphaeria cavernosa, D. versluysii, Neomeris annulata, Dictyota friabilis, and Ralfsai pangoensis (501).

Inshore areas appear sand-scoured and are devoid of corals. Outside the surf zone bottom relief increases and coral heads occur on elevated limestone surfaces. Numerous dead skeletons of Pocillopora meandrina nearshore, along channel margins, and around the outfall suggest occasional periods of unfavorable conditions (probably shifting sand during infrequent storm-wave events). Damage due to heated effluent (prior to relocation of the outfall) was localized (324). Corals tend to be more abundant south of the sand channel off the Kahe power plant than north of the channel. Prior to January 1980 storm damage, maximum coral cover above -30 feet (-10 m) was 60% (334). At present, total cover ranges between 10 and 30% (501). Porites lobata is the most abundant species throughout the area. Montipora verrucosa and M. patula are locally abundant at a depth of 6 feet (2 m) off Kahe Point. Porites compressa is co-dominant with P. lobata at a depth of 25 feet (7.5 m) directly seaward of the intake basin (42;334).

Coral coverage in the Kahe area has been decreasing since 1973 (501). An area of approximately 3.5 acres (1.4 ha) of live coral growth was destroyed directly or indirectly by construction of the offshore outfall for the Kahe plant. Further, overall declines in coral coverage in the Kahe area of 7% per year during 1973 to 1975, and 13% per year from 1975 to 1977 have been measured. The pronounced decline in coral coverage between 1975 and 1977 was believed to have resulted from disturbances associated with outfall construction and not operation of the offshore outfall. No significant decrease in coral cover occurred between 1977 and 1978 (334). Decreases in coral cover between 1978 and 1979 approached the high values of earlier perods when thermal effluent directly impacted on nearshore areas. However, during no time was there any indication of a spatial relationship between coarl mortality and proximity to the Kahe outfall (501).

A large decrease in total coral cover (nearly 60%) occurred between 1979 and 1980. The greatest coral damage occurred on deeper portions of the reef in areas subject to high wave energy and rates of sand deposition during January 1980 storm. High coral mortality also occurred north of the outfall along the margins of a sand channel in an area of relatively low coral cover. A large volume of sand (20 m^3 per day in 1980) has been deposited offshore of the outfall since 1976. Storm wave action spreads sand over reef areas south of the outfall causing decreases in coral affected by sand resuspension and deposition (501).

The primary cause of the dramatic coral decline off Kahe is undoubtedly wave disturbance from the powerful Kona storm which affected the area in early January 1980 (501). Following the storm, *P. compressa* fingers were almost entirely sheared off and *P. lobata* heads up to 1 m diameter were broken and overturned at intermediate depths. Little or no damage was noted in nearby shore areas, except north of the outfall where wave energy probably penetrated through a reef channel (334).

The fish fauna in waters near the Kahe power station have been surveyed extensively. A total of 183 species are recorded from the area (42). Species per transect are usually between 20 and 55 -- diversity (H') ranges from 0.61 to 3.01 (typically 2.5)(334). Among the most common are *Thalassoma duperreyi*, *Acanthurus nigrofuscus*, *Chromis vanderbilti*, *Ctenochaetus strigosus*, *Chaetodon fremblii*, *Chromis verator*, and *Mulloidichthys vanicolensis* (125). Additional frequently sighted species include *Canthigaster janthinopterus*, *Chaetodon miliaris*, *C. multicinctus*, *Cirrhitops fasciatus*, *Paracirrhites arcatus*, *Parupeneus multifasciatus*, *Pervagor spilosoma*, and *Sufflamen bursa* (334).

Substantial decreases in reef fish populations occurred in the reef areas most heavily impacted by the January 1980 storm. Post-storm surveys indicate that the natural castastrophe affected the reef fish community over a much wider area than did the Kahe outfall. Sand deposition continues to decrease the coral reef habitat available to reef fish. Decreases in fish population south of the outfall may continue through 1981 if sand moved inshore during the 1980 Kona storm accummulates on the bottom. However, recent observations indicate that sand deposited after the storm is being washed away from some areas.

WATER QUALITY

NEARSHORE WATERS

Nearshore waters are class "A" in Department of Health water quality regulations (189). Underwater visibility is usually very poor (5 to 10 feet) in shallow water fronting the sand beaches. Visibility improves only to around 25 or 30 feet offshore due to resuspension of sediments by waves. In water deeper than 40 feet, visibility is in the range of 60 to 80 feet (OCRI;139). However, visibility may be 100 feet or better at depths of 60 feet off the coast between Pili o Kahe and HECO Beach Park (139;236).

HECO THERMAL EFFLUENT DISCHARGE

Although the design depth for the heated water used for the cooling system of the Kahe power generating station was 27 feet (9 m), the present depth of discharge off Kahe Point is about 20 feet (7 m), as a result of sand deposited at the outfall. The discharge averages 861 mgd. The deep thermal diffuser was constructed to reduce the adverse effects of the heated water on inshore reef life, especially corals. HECO initially used a shoreline intake and outfall. The thermal plume flows west southwest under most weather conditions (501). The maximum areal extent of thermal alteration of surface temperatures (1.5°F; 0.83°C above ambient) in 1980 was approximately 190 acres (77 ha). The zone of mixing permit was modified by the Department of Health in 1980 to confirm with the maximum extent of the thermal plume (1125 acres) measured in 1976-1977 (504). In 1980, benthic temperatures more than 10°C above ambient (the NPDES permit limit) were limited to the immediate area of the discharged point source and seldom impinged on reef areas (501).

There is no indication of a relationship between coral mortality in the Kahe region and proximity to the outfall. Coral growth experiments demonstrate no adverse effects of thermal plume impingement (501). Thermal impingement above ambient along the rocky shoreline at Kahe Point does influence the composition and distribution of littoral assemblages. The effect is not considered adverse per se. Removal of the outfall to its offshore location has resulted in a restoration of the algal community in areas formerly receiving thermal discharge to a composition more closely resembling adjacent (unaffected) areas. However, the distribution and abundance of algal species in the immediate area of the outfall are influenced by thermal effluent. The total abundance of fishes near the outfall remains below pre-operational levels and the fish fauna off Kahe is influenced by proximity to the outfall. Nekton impingement by the Kahe Generating Station is generally inconsequential (334). Most fish species and age classes which enter the intake basins become entrapped. The most abundant fish in the intake forebays are _Prenesus insularum_ and _Kuhlia sandvichensis_ (501).

STREAM DISCHARGE

Several intermittent stream channels enter the ocean between Zablan's Beach (MAP 65) and Kahe Beach. Although these streams only flow a few times a year following heavy rains in the mountains, it is not unusual for nearshore waters to be discolored by red sediment for sometime afterwards.

USES

NANAKULI BEACH PARK - PILI O KAHE BEACH

Nanakuli Beach Park is split into two sections by an area of Hawaiian homestead land situated on a winding coastline of raised reef. The southern section was formerly known as Pili o Kahe Beach Park. It is connected to the former Kalaniana'ole Beach Park by a narrow right-of-way along the water's edge. The entire shoreline of the Pili o Kahe section is raised reef except for a small sand pocket in a cove at the south end of the park (39). This cove, called Pohakunui Beach (also "Muddy Feet") after a nearby street (139), is a good place for swimming when the ocean is calm. Sport divers regularly use the cove to gain access to offshore waters. However, winter swells create a turbulent shorebreak and strong currents that make the cove dangerous (39). Body surfers ride large winter and summer waves (86).

Net fishing occurs off Kahe (Manners) Beach and Pili o Kahe. Throw-netting for surgeonfishes, aholehole and other reef fishes is practiced from the raised reef terraces that dominate the coast toward Pili o Kahe.

KAHE (MANNERS) BEACH

The coastline behind Manners Beach is privately owned, but the beach is accessible by following the shoreline north from HECO Beach Park. The beach and water conditions are similar to those at HECO Beach to the south (39).

KAHE BEACH - HECO BEACH PARK (KEONE'O'IO)

A beach park north of the power plant, although owned and operated by HECO, is open to the general public. The wide sand beach continues offshore as a sand bottom, and the shorebreak is usually gentle. Nearshore waters are generally safe for swimming, although winter swells may at times result in large waves and attendant strong currents (39).

This coast is heavily fished, particularly at the HECO Beach Park and areas adjacent to the power plant intake and discharge basins. Pole fishing is the most popular method, with reef fishes, papio, ulua, and goatfish the major catches. In addition, a small fishery using poles and special tackle exists here for large awa.

KAHE BEACH PARK (BROWNS CAMP)

Kahe Beach Park is on a low terrace of raised reef south of the HECO power plant. The area was once known as "Browns Camp". There is no easy access to the ocean for swimming except by following a narrow path along the rock ledge to a small rocky cove 150 yards south of the improved park area. Swimming and diver entries and exits are possible in this cove on calm summer days, but the arrival of winter swells brings potentially dangerous surf and currents to this coast. Campers and shore fishermen use this park (39).

OFFSHORE WATERS

The major attraction for sport divers is the rich coral growth offshore between Pili o Kahe Beach and the HECO power plant. Commercial dive shops run charters to the waters off Nanakuli Beach Park. The bottom slopes gradually from shore and the area is a good place for novice divers and snorkelers. Two sunken airplanes lying offshore of Pili o Kahe Beach attract SCUBA divers and dive charters organized by commercial dive shops. Conditions for underwater photography are excellent in deep water offshore. At distances beyond 600 feet from shore, a strong surface current, called the "Barbers Point current", requires caution by divers (139;236).

The surf break off the Pili o Kahe section of Nanakuli Beach Park infrequently provides good paipo board and body surfing for young people (86). A surf break ("Tracks") off Kahe Beach offers consistently good board and body surfing. The shallow bottom is a potential hazard. The small waves off Kahe Point, although not particularly good for board surfing, offer good paipo board and body surfing most of the year. Sharks are sighted by surfers in these waters, but the major conflict has been construction of a deep thermal diffuser offshore from HECO's power plant (86). Construction required installation of a temporary sheet piling offshore of the facility. Shallow waters along this coast are popular with shell collectors (375).

Spearfishing occurs off the entire coast. Ornamental fish collecting is a major offshore fishery. Lobster (Panulirus sp.) is trapped commercially offshore (150).

STUDIES AND SURVEYS

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42 - Coles and McCain (1973): Baseline environmental conditions preceding expansion of Kahe plant to five units and construction of offshore outfall. Sta. 4A-10D of thirty-nine between Manners Beach and south of Kahe Point. Water temperature and turbidity, sedimentation, corals, micro-molluscs, zooplankton, and fish (transects, trapping, pathology). ((334))

124 - McCain and Peck (1972): Visual fish survey transects off Kahe Generating Station. ((42))

125 - McCain and Peck (1973): Fish surveys off Kahe Generating Station. ((42))

137 - Marine Advisors (1964): Littoral processes (sand movement), offshore bathymetry, bottom conditions off Kahe Point to Pili o Kahe.

168 - Richmond and Mueller-Dombois (1972): p. 386, fig. 2.9. Transect 9 of twenty-three around O'ahu in study of coastal plant assemblages.

324 - Jokiel and Coles (1974): 1971/72 surveys of coral coverage and condition off (former) HECO Kahe thermal discharge. ((334))

331 - URS (1973): Impact studies for Kahe Poweb Plant discharge on the marine environment. Summaries of environmental baseline data.

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376 - R.M. Towill Corp. (1974, 1977a, 1977b, 1979, 1980): App. A. Program monitoring beach profiles and offshore sand reservoirs. Offshore sand depth and on-going beach profiles (1 to 7 of nine between Kahe Point and Kalaniana'ole Beach). ((334))

381 - Char and Balakrishnan (1979): Botanical survey of the 'Ewa Plain.

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502 - Stearns-Roger, Inc. (1973): Environmental impact Assessment for expansion of the Kahe power plant to 6 generating units.

503 - Coles and Fukuda (1975): Baseline environmental conditions preceeding expansion of Kahe power plant to 5 units and construction of offshore outfall.

504 - McCain (1977): 1977 NPDES final report analyzing marine environmental impact of Kahe offshore outfall.

505 - Hawaiian Electric Co. (1976): Interim report describing conditions resulting from offshore outfall construction.

506 - B.K. Dynamics (1971): Marine environmental impact analysis, Kahe Power Plant.

508 - Coles (1979b): Annual Report. Kahe Generating Station NPDES Monitoring Program.

MAP 67 - LANIKUHONUA BEACH (WEST BEACH)

(KAHE POINT, KAHE BEACH PARK, LANIKUHONUA BEACH)

- Ewa Quadrangle
- POD, 1:6000 BW, 1:

PHYSIOGRAPHY

'EWA PLAIN

The broad coastal plain south and east of Kahe Point to Pearl Harbor (MAP 76) is the 'Ewa Plain, composed of emergent reef and marine sediments deposited during a previous higher stand of the sea (128;209). Sinkholes occur in some areas along the coast, formed by dissolution of the limestone exposed to fresh water. Irregular masses and abrupt ridges of fossil reef are common (381).

KAHE POINT

The coast at and south from Kahe Point is a ledge which lies 15 to 20 feet (3 to 5 m) above sea level and is topped in places by a rampart of large reef boulders, presumably thrown up to this height by exceptional storm waves. Inland from the rampart is an old storm beach about 20 to 25 feet above present sea level, sparsely vegetated and elevated in places by wind-blown dune sand (244;324). The only beach along this stretch is a pebble beach found in a small cove south of the improved portion of Kahe Beach Park.

LANIKUHONUA (WEST) BEACH

The coast south of Kahe Beach Park is property of the Campbell Estate. This section is called Lanikuhonua, after the name of the the nearby beach estate of the late Alice Kamokila Campbell. A developer has renamed the area "West Beach". The coast is generally similar to that around Kahe Beach Park: a terrace of raised reef formed when sea level was higher than at present. The platform is interrupted by three well-protected coves. Large boulders form ramparts across the mouths of the coves, backing up sea water in "lagoons". The waters are renewed by waves spilling over the low, seaward ramparts. Sand beaches occur along the heads of these coves (108). There appears to be no long-term erosion of one of the pocket beaches at north Lanikuhonua between 1949 and 1971 (Whang, 1981). The tsunami of 1960 caused runup to an elevation of 9 feet (3 m) at Lanikuhonua (329).

OFF KAHE POINT

A major sand channel seaward of the HECO discharge basin (MAP 66) connects with an extensive sand body offshore. A second sand channel lies offshore to the south. Between the channels there is a narrow sloping shelf of limestone (334).

OFF LANIKUHONUA BEACH

A broad, submerged reef platform between Kahe Point and Lanikuhonua has high vertical relief and little sand cover (108;351). Within 100 m of shore, this bottom merges with an area dominated by sand and sand-scoured limestone (water depth 2 to 3 m). Sand pockets are more common toward Kahe Point, where they extend seaward in a broken maze that coalesces as one large sand deposit near the 18 m depth contour. The shallow inshore portion of the platform is pitted with potholes (to 1 m across). Seaward are surge channels which run perpendicular to shore. Nearshore, channel walls rise steeply from depths of 4 to 10 m to within 2 m of the surface. Offshore, channels are as deep as 5 m (509). Coral rubble, mostly from *Porites compressa* heads, is conspicuous in deep water (321). The submerged limestone shelf extends from 1800 to 4200 feet (600 to 1400 m) offshore, varying in depth between 10 feet (3 m) near shore to only 50 feet (15 m) along the outer edge. The shelf terminates offshore as a ledge and drop-off that descends steeply to depths of 65 to 80 feet (20 to 25 m). Below the drop-off the bottom consists of sand, scattered rubble, and isolated limestone outcrops (108).

South of Lanikuhonua Beach toward Barbers Point Harbor (MAP 68), the bottom is featureless limestone often covered by a veneer of rubble and sand in small depressions. The bottom is strewn with occasional large limestone slabs (108;509).

FLORA AND FAUNA

KAHE POINT BEACH PARK

The rare coastal plant *Capparis sandwichiana* var. *Zuharis* (mai'a pilo) is reported in only 2 locations in O'ahu, including Kahe Point Beach Park (510).

OFFSHORE SOUTH OF KAHE POINT

Coral growth on the submerged reef shelf off Kahe Point is luxuriant, particularly in shallow waters fronting Kahe Point (MAP 66)(108;324) and at depths greater than 12 feet (4 m) over most parts of the shelf prior to a major storm in January 1980. Cover ranged from 30 to 60 % and, in places in water below -25 feet (-8.5 m), approached 100% cover (42;334). At present, total cover is between 10 and 30 % (501). The coral assemblage is dominated by *Porites lobata*. Large heads occur nearshore, grading to smaller heads offshore (108). *Pocillopora meandrina* is abundant and occasionally dominant in water 6 to 12 feet (2 to 4 m) deep, as well as on the deeper limestone bottom adjoining the large sand deposit offshore (42). Numerous dead *Poc. meandrina* heads occur in some areas. *Leptastrea purpurea*, *Pavona duerdeni*, and *Montipora verrucosa* are reported as common in localized patches in shallow water and *Montipora patula* is locally abundant farther offshore (42). Amansia glomerata is common in addition to the ubiquitous species listed off Kahe (see MAP 66)(334).

OFF LANIKUHONUA

The shallow (less than 2 m) limestone and sand covered bottom fronting Lanikuhonua Beach has only moderate coral cover (13 to 18%). The dominant species is Porites lobata growing in small encrusting or prostrate forms (509). Pocillopora meandrina is also conspicuous. The soft coral, Palythoa tuberculosa, is locally abundant in shallow water. At depths between 15 and 30 feet (4 to 10 m), where there are fewer sand pockets and more bottom relief, coral cover varies between 20 and 50% (42;108;501; 509). Although conspicuous invertebrates are not especially abundant, the sea urchins, Tripneustes gratilla and Echinometra mathaei, and the tubeworm, Spirobranchus sp., are common (108). Algae are inconspicuous, except for the encrusting corraline, Lithothamnion sp. At least 30 fish species occur, the most abundant being the surgeonfishes, Acanthurus nigrofuscus, Ctenocheatus strigosus, and the wrasse, Thalassoma duperreyi. Species which are locally abundant include Zebrasoma flavescens, Melichthyes niger, and Chaetodon multicinctus (509).

Below -30 feet (-10 m), Porites compressa is dominant, although P. lobata is still very abundant. Many heads of P. compressa are broken, apparently extensively damaged by storm waves. Macroinvertebrates are very abundant in the areas dominated by P. compressa. Most common are the sea urchins, Tripneustes gratilla, Eucidaris metularia, and Echinometra mathaei. Porolithon sp. dominates the algal assemblage, followed in abundance by Amansia glomerata, Desmia sp., and Galaxaura sp. (108).

A diverse and abundant fish assemblage is found in association with the lush coral bottom south of Kahe Point. In areas dominated by P. lobata, the most abundant species are Acanthurus nigrofuscus and Ctenochaetus strigosus (108). Thallasoma triostegus is sometimes abundant (509). Common fishes include Chaetodon multicinctus, Pervagor spilosoma, Parupeneus multifasciatus, and Myripristis sp. Two uncommon species of butterflyfishes (Chaetodon ephippium and C. reticulatus) are reported (108;509). The fish fauna is better developed around P. compressa-dominated bottoms. Ctenochaetus strigosus is most abundant, but a variety of other species are common including Zebrasoma flavescens, Centropyge potteri, Chromis verator, C. ovalis, and several smaller damselfishes (Chromis hanui, C. vanderbilti, and Plectroglyphidodon johnstonianus). Two uncommon reef fishes observed here are Forcipiger longirostris and Centropyge loriculus (108).

OFFSHORE SOUTH OF LANIKUHONUA BEACH

The shallow limestone bottom south of the Lanikuhonua Beach area has coral cover varying from 9% (108) to 17 to 25% (509). Porites lobata predominates. The uncommon Montipora verrilli also occurs here (509). Corals, invertebrates, and associated fishes are most numerous in shallow pockets or depressions in the flat limestone bottom. Conspicuous invertebrates are moderately abundant, particularly the starfish, Linckia multifora. The lace coral, Triphylozoon hirsutum is reported as common. Thalassoma duperreyi, Chromis vanderbilti, and Ctenochaetus strigosus dominate a moderately abundant assemblage of fishes. The hawkfish, Paracirrhites arcatus, is abundant. Halimeda discoidea, Amansia glomerata, and Martensia sp. are the most frequently observed algae on the flat limestone surface (108). At least 26 species of fish inhabit shallow waters (2 m). Most abundant are the surgeonfishes, Ctenochaetus strigosus and Acanthurus nigrofuscus, the wrasse, Thalassoma duperreyi, and the damselfish, Stegastes fascialatus.

Numerous green-sea turtles are reportedly present at depths between 30 and 50 feet south of Lanikuhouna Beach (509;511). Coral cover is high (55 to 80%) at depths of 5 to 10 m. Porites lobata and Montipora patula are the most common species. Other macroinvertebrates are not abundant. At least 44 fish species are recorded from this depth range. Most common are the surgeonfish, Acanthurus dussumieri, A. triostegus, A. nigrofuscus, A. olivaceous, A. strigosus, Ctenochaetus strigosus; the butterflyfish, Chaetodon multicinctus; the damselfishes, Abudufduf abdominalis, Chromis vanderbilti, and Stegastes fasciolatus.

At greater depths (9 to 12 m), coral cover decreases and is dominated by Porites lobata growing in large heads (5 m across) which are spaced far apart. Most other species are small. A number of commercially important fish species inhabit this area. Spiny lobsters (Panulirus penicillatus) and slipper lobsters (Paribaccus antarticus) are relatively common. Large P. lobata colonies provide shelter for diverse macroinvertebrates and at least 44 species of fishes, the most common of which are the surgeonfishes Acanthurus nigrofuscus and Ctenochaetus strigosus, the wrasse, Thalassoma duperreyi, and the goatfish, Parupeneus multifasciatus.

Coral cover is low (2 to 5%) on the sand-scoured surfaces near the seaward edge of the limestone platform (12 to 18 m depth). Pocillopora meandrina is most common; Poc. eydouxi is also present. Other macroinvertebrates are rare but include the commercially valuable Octopus cyanea and Panulirus marginatus. Fishes are not abundant (509).

BOTTOM BELOW -50 FEET

Fishes are numerous along the steep drop-off between -50 and -70 feet (-15 to -25 m), but Porites lobata is the only coral and cover is low. The starfish, Linckia multifora, is common and commercially important invertebrates (i.e., lobster, Panulirus sp., and octopus, Octopus cyanea) are present in moderate abundance. The fish fauna is dominated by species associated with deeper water (e.g., Chromis hanui, Chaetodon kleini, and Anthias thompsoni). Small jacks (ulua) frequent the area. Several unusual species occur, including an unnamed *Anthias* sp. and *Malacanthus brevirostris* (108).

WATER QUALITY

NEARSHORE WATERS

Nearshore waters are classified "A" in Department of Health water quality regulations (189). Water clarity is generally excellent, and coastal waters may be described as pristine, well-flushed and minimally affected by terrestrial runoff. Storm events no doubt increase runoff into coastal waters (509). Underwater visibility is quite variable, depending on surge and possibly tidal currents. Average visibility is reported as 55 feet (17 m)(108).

USES

KAHE POINT BEACH PARK

Pole fishermen are the primary users of the long shoreline of raised reef and especially at Kahe Point Beach Park (formerly known as "Brown's Camp"). The only easy access to the ocean for recreational swimming or diving is at the back of a small cove south of the improved park. Campers frequent the backshore area of Kahe Point Beach Park (39). Although nearshore waters are usually safe, water conditions become hazardous when southwest or northwest swells bring high surf to this coast (108).

LANIKUHONUA - WEST BEACH

There is no public access to the Campbell beach estate south of Kahe Point Beach Park and access to the shoreline is difficult (except at the "lagoons") because of an elevated reef rock formation. Limited shoreline access is possible from the north by following the shoreline from Kahe Beach Park and by following canefield roads which can be entered through locked gates for which certain plantation emloyees may obtain keys. The most commonly used entrance is the road to Campbell barge harbor from the south. However, this section of coast is presently undergoing development.

Limited access to the Lanikuhonua Beach section of coast reduces fishing activity. Pole fishing is the predominant fishing method along the coast south of Kahe Point, with reef species as the main catch. The shoreline is noted as a good area for moi. Throw-net fishermen visit the raised reef shoreline. Swimming in the "lagoons" along the shore is popular with young people because of the protection provided by the outer rock walls (39).

OFFSHORE - KAHE POINT TO LANIKUHONUA

Diving conditions in the waters off Kahe Point and south past Lanikuhonua Beach are excellent throughout most of the year. Commercial dive shops run advanced SCUBA classes and charters in the waters off Kahe Beach Park. This area is being considered as a marine life conservation district because of the lush coral growth offshore (206). Although inshore waters are usually very safe, currents are predominantly tidal and can be strong in deep water. Novice divers should use caution beyond 200 yards from shore (108;236). Spearfishermen find an abundance of fish around the coral bottom offshore, as well as along the face of the drop-off below -50 feet (-15 m). Squidding is undertaken and lobster (Panulirus sp.) are trapped commercially in deep water (150). Pole fishing from boats is common offshore.

Surf breaks offshore of the Brown's Camp section (south of Kahe Point) and Lanikuhonua offer good board and belly-board surfing potential in the winter but are rarely used because of poor access (86). Shallow water off this coast is noted for shell collecting (375).

STUDIES AND SURVEYS

16 - Bathen (1978): p. 65, fig. 15. Compilation and analysis of offshore water circulation data. Additional references.

42 - Coles and McCain (1973): Sta. 1A-4B of thirty-nine between Manners Beach and south of Kahe Point. Data on water temperature and turbidity, sedimentation, corals, micromolluscs, zooplankton, and fish (transects, trapping, pathology). ((334))

108 - Kimmerer and Durbin (1975): p. 51-56, figs. 16, 17, various tables and graphs. Averaged results of benthic survey transects in five zones offshore of Kahe Beach Park and Lanikuhonua. Substratum types, corals, macroinvertebrates, fishes. Area use considerations.

137 - Marine Advisors (1964): Littoral processes (sand movement), offshore bathymetry, bottom conditions off Kahe Point.

321 - URS (1972): Survey of marine areas off Kahe Power Plant. Water temperature, sediment distribution, beach description, heavy metals analyses, biological surveys including plankton and benthos, and foraminifera distribution. ((331)).

334 - Coles (1979): Summary of data collected relevant to the impact of the Kahe Generating Station on the marine environment. Description of the power station, temperature studies, benthic surveys of algae, corals, reef fishes.

351 - URS (1973): Impact studies for Kahe Power Plant discharge on the marine environment. Summaries of environmental baseline data. ((334))

500 - Whang (1981): Study of Lanikuhonua Beach width over 30-year span using aerial photographs.

509 - Bienfang and Brock (1980): Quantitative benthic sampling to a depth of 18 m at stations 4-6, 8, 11-17 (of seventeen). Measurement of 8 water quality parameters at stations 2-6, 8-9 (of nine).

510 - Tabata, in press: The native coastal flora of O'ahu, Hawai'i.

511 - Ad Hoc Committee on the Advancement of OTEC for Hawaii (1980):

MAP 68 - BARBERS POINT HARBOR

(BARBERS POINT BARGE HARBOR, CAMPBELL INDUSTRIAL PARK)

- Ewa Quadrangle
- POD, 1:6000 BW, 1:

PHYSIOGRAPHY

BARBERS POINT HARBOR

Barbers Point Harbor (Campbell Barge Harbor, Malakole Harbor) is a 9-acre body of water which was quarried out of the raised reef that forms the broad 'Ewa plain (see MAP 67). Boulders accumulated around the perimeter of the harbor as a result of the dredging form a rubble slope of considerable relief at depths of 15 to 20 feet (5 to 7 m). The central harbor basin, 25 feet (8 m) deep, is covered by a 2-foot layer of mud. The harbor experiences considerable wave surge (322).

OFF BARBERS POINT HARBOR

A flat pavement of consolidated reef rock extends from shore to a depth of about 20 feet (7 m). The limestone bottom increases in relief below -25 feet (-8 m) as a result of patches of dead and living coral. At around -30 feet (-10 m) there is a ledge above a steep-sloping limestone cliff that drops 12 to 15 feet (4 to 5 m) to accumulated rubble talus over a limestone surface thinly covered by sand. Beyond -45 feet (-15 m) there is a gradually sloping bottom of thick sand deposits, interrupted by patches of rubble and occasional large boulders (322).

Directly seaward of the harbor entrance is a rubble bottom created by channel dredging and extending to a depth of about 26 feet (8 m). Beyond the marked channel, the limestone bottom has generally high relief and is veneered by small, scattered patches of sand and rubble (322). A small area north of the barge harbor is differentiated from the rest of the bottom by the presence of winding ridges of dead coral (Porites compressa) which project vertically about 1 m and are between 2 and 10 m in width. The ridges, which lie between 80 to 170 m offshore, are seperated by depressions 1 to 5 m in width (509).

FLORA AND FAUNA

COASTAL PLAIN

The 'Ewa Plain harbors a type of brackish water environment termed "anchialine" -- pools fed by ground water in highly permeable limestone strata. In this area the pools occur in sinkholes near the coast. Fossil evidence of prehistoric, flightless birds (now extinct) has been recovered from one sinkhole near the harbor. Populations of a small, red shrimp (Halocaridina rubra) occur in the anchialine pools (379).

Several coastal strand plants proposed as endangered species are found growing in undeveloped areas in the vicinity of Barbers Point Harbor. Achyranthes splendens var. rotundatum is present on military lands south of the harbor. Euphorbia skottsbergii var. kalaeloana, once thought to be extinct, is found in three major colonies the proposed harbor expansion area. The largest colony is located along the margin of a limestone quarry near the barge harbor. Gossypium sandvicense occurs with the other species in kiawe forest areas (379;381). Plans are underway to propagate the rare variety of Euphorbia in other areas.

NORTH OF BARBERS POINT HARBOR

Coral cover averages 6% in shallow waters (2 to 3 m) north of the barge harbor. Porites lobata is most abundant. The sea urchins, Echinometra mathaei and E. oblongata are conspicuous. At least 17 species of fish are present, the most common being the surgeonfishes, Acanthurus nigrofuscus, A. triostegus, Naso unicornis, and the damselfish, Chromis vanderbilti (509).

At greater depths (9 m), coral cover is variable, ranging from 23 to 65%. Porites lobata is most abundant, followed by P. compressa. At least 45 fish species occur, the most abundant being the surgeonfish, Acanthurus nigrofuscus, Ctenochaetus strigosus, and Zebrasoma flavescens; the damselfish, Chromis vanderbilti, Stegastes fasciolatus, and Plectroglyphodon johnstonianus; the wrasse, Thalassoma duperreyi; and the goatfish, Parupeneus multifasciatus.

Coral cover ranges between 16 and 30% near the seaward edge of the limestone platform (15 m depth). Porites lobata is most common, and the deep water button coral, Cycloseris vaughani, is present. Other macroinvertebrates are locally abundant, particularly the sea urchin, Echinostrephus aciculatum. The fish fauna consists of at least 23 species (509).

A small area distinguished by winding ridges of dead coral is overgrown by encrusting coralline algae. Live coral cover ranges from 28 to 57%. Porites lobata is most common. P. evermanni, P. pukoensis, P. compressa, and Montipora patula are locally abundant. At least 23 species of fish inhabit the area. Only Acanthurus nigrofuscus, Thalassoma duperreyi, and Stegastes fasciolats are common (509).

BARBERS POINT HARBOR

The upper 2 meters of the harbor's quarried walls supports a well developed algal turf. Corals occur on the rubble slope around the harbor margin at depths of 15 to 20 feet (5 to 7 m). Total cover is 8 to 16 %. Small colonies of Pocillopora damicornis and Montipora verrucosa are the most prevalent species. Cyphastrea ocellina is the most common species on boulders in the more silted regions. In general, coral colonies inside the harbor tend to be larger than those on limestone substratum outside the harbor (322).

The abundance of filter-feeding invertebrates such as tunicates, sabellid worms, sponges, vermitids, and oysters increases with the degree of protection and siltation in the harbor. Numerous sea urchins (especially Echinometra mathaei) are present on the harbor walls and ophiuroids are common. However, no conspicuous macroinvertebrates are seen on the mud floor of the harbor (322).

Thirty-five species of fish are recorded from inside the harbor, but the assemblage is dominated by juveniles, especially those of Thalassoma duperreyi, Stethojulis balteata, and Stegastes fasciolatus (322).

OFF BARBERS POINT HARBOR

The limestone pavement extending from shore has coral cover ranging from 8 to 20 %. Where bottom relief increases below -25 feet (-8 m), corals are more abundant and bottom cover ranges from 25 to 46 %. Along a ledge at -30 feet (-10 m) coral cover is around 9 to 20 % of the bottom, decreasing to 6-10 % on the face of an adjacent escarpment. Coral cover on the sand and rubble plain below the submarine cliff is generally less than 2%, although corals are locally abundant in the centers of large rubble patches. The dredged channel entering Campbell Harbor has very sparse coral cover (less than 1%). In all locations, Porites lobata is the dominant species, occurring in very large heads in areas of high relief. Montipora spp. are also very common. The soft coral, Anthelia edmondsoni, is abundant on the pavement south of the barge harbor. The sea urchin, Echinometra mathaei, is common throughout the area, but is most numerous on high-relief bottoms and on the rubble bottom created by channel dredging at the entrance to Campbell Harbor (322).

An abundance of fishes occurs along the ledge and over the coral-rich bottom below -25 feet. Some 65 species are recorded from these areas compared to 34 species associated with the flat limestone bottom in shallow water and only 17 species associated with the rubble bottom entrance channel. The most numerous species in these waters are Chromis vanderbilti, Thalassoma duperreyi, Acanthurus nigrofuscus, A. nigroris, Pervagor spilosoma, Ctenochaetus strigosus, and Stegastes fasciolatus. At least 57 species are found near the base of the drop-off at -45 feet (-15 m), but this fish assemblage is associated with large boulders strewn on the otherwise featureless bottom. Pseudojuloides cerasinus, Pervagor spilosoma, and Chromis vanderbilti are most abundant (322).

OFF CAMPBELL INDUSTRIAL PARK

A lengthy list of fish species is recorded in waters to depths of 85 feet (26 m) offshore of Campbell Industrial Park.

Inshore waters no deeper than 5 feet have a fish fauna generally dominated by sand-bottom species. _Mugil cephalus_, _Neomyxus leuciscus_, _Acanthurus triostegus_, _Polydactilus sexfilis_, _Stethojulis balteata_, and _Kuhlia sandvicensis_ are most abundant from a list of 41 species. Although fishes are less abundant offshore at depths between 15 and 55 feet (5 to 17 m), a fairly diverse fauna totaling at least 53 species is present. _Acanthurus triostegus_, _Myripristis_ sp., _Adioryx xantherythrus_, and _Apogon kallopterus_ are common species. At depths of 70 to 85 feet (21 to 26 m), the fish assemblage totals 53 recorded species, but these are deeper water forms, such as _Sufflamen bursa_, _Cantherhines verecundus_, and _Canthigaster jactator_ (323).

WATER QUALITY

BARBERS POINT HARBOR

Water quality deteriorates rapidly approaching Barbers Point Harbor, where groundwater influence on coastal water is evident. Turbid waters occurring nearshore can be observed moving north from the industrial park area during ebbing tide conditions (509). Present DOH water quality regulations designate Barbers Point (Campbell) Harbor waters as class "B" (189). Proposed revisions to these regulations promulgated in accordance with "208 Areawide Waste Treatment Management" planning would reclassify the harbor as a class "A" embayment, and the bottom subtype would be "artificial basin" (307). Water quality in the harbor is generally good as a consequence of the excellent flushing characteristics of the basin and infrequent barge traffic. Low salinity groundwater flowing through the porous limestone of the 'Ewa Plain seeps through the walls of the harbor and a constant seaward surface flow is present. Springs carry nutrient-enriched tailwaters from upland canefield irrigation, although the rapid dilution minimizes biostimulatory impacts. Barge traffic stirs up soft bottom sediments, but the rapid flushing dissipates the turbidity within a tidal cycle (322).

NEARSHORE WATERS

Coastal waters are classified "A" in DOH water qualidy regulations (189). Chevron Refinery discharges 4.24 mgd of industrial wastewater into the waters west of Barbers Point (186). Nutrient-enriched ground water flowing from irrigated sugar cane fields on the 'Ewa Plain seeps into the ocean through the walls of Barbers Point Harbor (322). Drainage from a feedlot operation in the industrial park may be a source of nutrient-laden runoff.

USES

BARBERS POINT HARBOR

Barbers Point (Cambell) Harbor, quarried into the plain of emergent reef rock, is primarily a privately-owned barge harbor serving Campbell Industrial Park. Fishing boats use the harbor to some extent and it serves as an emergency refuge for small boats during stormy weather. Use of the private barge harbor and launching ramp by fishermen is restricted to permit holders. Enlargement of the basin and other construction is proposed that would convert the present harbor into a deep-draft port. Bait-fish are collected in the harbor. Fishing activity is heavy around the harbor, especially around the pier and entrance channel. A permit from the Campbell Estate is required. The predominant method employed is pole fishing and ulua, papio, aholehole, 'o'io, goatfish, surgeonfish, and snapper are the primary targets.

SHORELINE

The raised reef shoreline south of the harbor is recommended as a nature study area for public schools (332). Access to the shoreline is somewhat limited but possible via tracks leading off the main highway through Malakole Military Reservation. The barge harbor provides the best access to the ocean shore along Malakole Military Reservation and Kamokila Campbell Estate. Fishing activity is light to moderate along most of the coast, except at the barge harbor where fishing is heavy. Shorecasting for reef fishes occurs along the coast but it is limited by access and diminishes in intensity away from the barge harbor. Some throw-netting occurs near the harbor.

OFFSHORE

A surf break offshore Camp Malakole has excellent potential for board and paipo-board surfing but it is seldom surfed because of the restrictions on access along this section of coast. The rocky shoreline poses a potential hazard (86).

Spearfishing and net fishing are infrequent in these waters. Pole fishing is undertaken from boats in offshore waters. Commercial trapping for lobster is carried out in the area of the offshore drop-off and ledges (150). Octopus are caught in deep water. The area around the outer margin of the submerged reef, at depths between -20 and -50 feet, is regarded as excellent for shell collecting (375).

STUDIES AND SURVEYS

16 - Bathen (1978): p. 65, figs. 15 & 26. Compilation and analysis of offshore water circulation data. Additional references.

117 - Long (1972): Site 2 of three off leeward coast of O'ahu in fouling study using test panels suspended beneath a buoy in 108 feet (33 m) of water, 1.3 km. offshore, from March 1969 to May 1972. ((65))

322 - ECI (1975): Water quality, water circulation, salinity, temperature, and benthic transects (corals, macroinvertebrates, fishes) in and offshore of Barbers Point Barge Harbor in October 1975.

341 - Kimura and Nagata (1979): Description of strand vegetation.

380 - Herbst (1976): app. B-2. Terrestrial vegetation survey.

381 - Char and Balakrishnan (1979): Botanical survey of the 'Ewa Plain.

509 - Bienfang and Brock (1980): Quantitative benthic sampling to a depth of 18 m at stations 1-3, 9-10 (of seventeen). Measurements of 8 water quality parameters at stations 1 and 7 (of nine).

MAP 69 - BARBERS POINT (KALAELOA)

(BARBERS POINT, BARBERS POINT BEACH PARK)

- Ewa Quadrangle
- POD, 1:6000 BW, 1:

PHYSIOGRAPHY

COASTLINE

The shoreline passing around Barbers Point (Kalaeloa) is almost entirely a shelf of solution-pitted emergent limestone. (Also MAP 66). The 1946 tsunami caused run-up to 12 feet at Barbers Point (329).

OFF BARBERS POINT

The bottom offshore is a submerged reef extending 1,500 to 2,000 feet (450 to 600 m) before dropping through a series of terraces to deep water. The reef is predominantly consolidated limestone with scattered potholes and sand pockets. In deep water, rubble slopes bank against the lower portions of steep dropoffs. The nearly level terraces are sand with scattered patches of rubble (323).

FLORA AND FAUNA

'EWA COASTAL PLAIN

A coastal strand vegetation, characterized by a shrub form of Myoporum sandwicense (naio), Capparis sandwichiana var. Zoharyi (maiopilo), Chenopodium oahuens var. rotundatae, and Achyranthes splendens probably once occupied much of the coastal plain around Barbers Point. Today this vanishing assemblage is found on a few acres behind the lighthouse and in scattered locations in the industrial area (113;341). Rare or endangered plants found here include Euphorbia scottsburgii var. kalaeloana, Achyranthes splendens var. rotundata, Myoporum sandwicense var. stellatum (recommended for endangered species designation), Eragrostis paupera, and Scaevola coriacea (380;381;401). Other strand species present are Sesuvium portulacastrum ('akulikuli), Lycium sandwicense ('ohelo kai), and Fimbristylis pycnocephala (381). Barbers Point is one of two locations from which the rare Capperis sandwichiana var. Zoharyi is reported (510).

OFF BARBERS POINT (WEST)

Pocillopora sp., Porites sp., and Montipora spp. are reported to be the more common species of corals off Barbers Point. Cover is sparse (323).

WATER QUALITY

NEARSHORE WATERS

Coastal waters are rated "A" in Department of Health water quality regulations (189). The Chevron Refinery discharges 4.24 mgd of industrial wastewater west of Barbers Point (186). Hawaiian Milling Corp. has a DOH permit for emergency discharge of stormwater runoff (309). The Hawaiian Independent Refinery treats refinery wastes via an oxidation pond system and disposes of the treated water in an injection well. Some cesspools are present along the coast (219). Nutrient-enriched ground water from upland sugar cane fields seeps into coastal waters through springs in the porous raised reef that forms the 'Ewa coastal plain (322).

USES

BARBERS POINT - 'EWA PLAIN

The coastal plain north and east of Barbers Point is occupied by Campbell Industrial Park. A lighthouse is located at the Point.

BARBERS POINT - BARBERS POINT BEACH PARK

Access to much of the shoreline around Barbers Point is difficult because of the industrial park occupying the coastal plain. Although far from Farrington Highway, Barbers Point Beach Park is a point of access used mostly by fishermen. Because of limited access, fishing activity is light along most of this coast -- Barbers Point Beach Park being the exception. Pole fishing is the predominant fishing type, although some throw-net fishing and spearfishing occur off the shore.

Barbers Point Beach Park is a poor swimming area: the only sand shore is a short stretch located west of the park. Inshore waters are generally safe during the summer months, but occasional southwest swells cause high surf and dangerous currents in the winter (39). Consistent surf breaks offshore of the oil refinery and cement plant in the industrial park offer good surfing. The rocky shore is a potential hazard and use is limited by poor access (86).

OFF BARBERS POINT

Divers, particularly spearfishermen, frequent offshore waters. The main attraction is an abundance of fish associated with deep ledges and drop-offs. Generally sparse coral cover and a flat, featureless bottom near shore provide few attractions for recreational diving.

Pole fishing for reef fishes offshore is undertaken from boats. Steep drop-offs harbor lobster which are trapped commercially in this area (150). Octopus are also caught in deep water from boats.

A restricted anchorage has been established offshore for exclusive use of tanker vessels unloading oil through a submarine pipeline to Campbell Industrial Park.

STUDIES AND SURVEYS

16 - Bathen (1978): p. 64-6, figs. 15 & 26. Compilation and analysis of offshore water circulation data. Additional references.

168 - Richmond and Mueller-Dombois (1972): p. 387, figs. 1, 2 & 8. Transect 8 of twenty-three around O'ahu in study of coastal plant assemblages.

323 - Industrial Bio-test Laboratories, Inc. (1972): Currents, water chemistry, zooplankton, chlorophyll a, algae (including solution bench samples), invertebrates (littoral and sublittoral), and fishes. Observations made mostly in Nov.-Dec. 1971 and April 1972 off proposed refinery site.

341 - Kimura and Nagata (1979): Description of strand vegetation.

380 - Herbst (1976): app. B-2. Terrestrial vegetation survey.

381 - Char and Balakrishnan (1979): Botanical survey of the 'Ewa Plain.

510 - Tabata (in press): The native coastal flora of O'ahu, Hawai'i.

PART 2: LITERATURE REVIEW OF THE PHYSICAL, CHEMICAL AND BIOLOGICAL OCEANOGRAPHIC PARAMETERS PERTINENT TO OTEC DEVELOPMENT AT KAHE POINT, OAHU

OFFSHORE PHYSIOGRAPHY

General bathymetry of the Kahe OTEC region is described in Pararas-Carayannis (1965). Water depth increases gradually to approximately one mile offshore, where depths reach 100 to 200 m (330 to 650 feet). Depth then increases rapidly, as a relatively steep scarp extends down to about 500m (1,600 feet) at about 1.5 miles from shore. Beyond the 500m depth, the bottom slope of the Lualualei Shelf is more gradual, increasing 100m with every 0.4 to 0.5 mile increment of distance from the shore.

Two submarine shelves, the Lualualei Shelf (-1,200 to -1,800 feet) and the Waho Shelf (-3,000 to -3,600 feet) are apparently present further offshore. The Lualualei shelf is about one mile in width. A moderate slope drops down to the Waho Shelf at about -3,000 feet depth, approximately 3.5 miles offshore (Graf, 1980). Sediment thicknesses of 250-300 feet have been reported for the Lualualei Shelf (Stearns, 1974), and similar thicknesses are likely on the Waho Shelf (Graf, 1980).

From just north of Kahe Point to about one mile south of Maile Point, a depth of 914 m (3,000 feet) is reached approximately 3 miles from shore. North and south of this area, greater distances are required to reach this depth.

The characteristics of the bottom have not been described beyond a depth of 100 feet. However, the Kahe area is likely to be similar to the offshore area between Kepuhi Point and Ka'ena Point. Here, nearly level plateaus at depths of 20-30 m and 120-

150 m are connected by a steep escarpment. In the Kepuhi-Ka'ena area, the escarpment is penetrated by numerous wide sand channels that grade from one terrace to the other. The amount of offshore sand increases markedly toward the southern end of the Kepuhi-Ka'ena area, because of the southerly offshore transport of sand from nearshore beach systems. A similar southerly and seaward transport of sand from the Ma'ili-Kahe littoral cell is believed to result in thick sand deposits seaward of Kahe. Sand bodies at depths between 100 and 300 feet (30 to 100 m) have been surveyed using a seismic reflection technique. Sand is widespread in the depth interval between 120 and 180 feet (40 and 60 m) and covers virtually the entire bottom in the 180 to 300 foot (60 to 100 m) depth range. Interpretation of seismic penetration of sediment resulted in an estimate of 85 million cubic yards of sand offshore of the coast between Ma'ili Point and Barbers Point. Nearly half of this sand volume is in the 120 to 180 foot (40 to 60 m) depth range (Campbell, et. al., 1970).

WAVES, TIDES AND CURRENTS

Kahe is located approximately 20 miles from the Honolulu tidal station for which NOAA publishes daily predictions. Water elevation measurements made by HECO at the intake structure of the Kahe generating station indicate that Honolulu daily tidal predictions are adequate for the Kahe area (see Table 1).

Characteristics of the wave climate off Kahe have been described by Marine Advisors (1964). Breaking wave roses derived from a typical year are reproduced as Figure 2. Waves from the

TABLE 1. Tidal data for the Kahe Point area.

Location	Position		Differences				Ranges		Mean Level
	Lat.	Long	Time		Height		Mean	Diurnal	
			H.W.	L.W.	H.W.	L.W.			
	0 ' North	0 ' West	h.m.	h.m.	Feet		Feet		Feet
Honolulu	21-18	157-52	Daily Predictions				1.2	1.9	0.8
Waianae	21-27	158-12	+0 18	+0 15	0.0	0.0	1.2	1.8	0.8
Kahe (interpolation)	21-22	158-08	+0 12	+0 10	0.0	0.0	1.2	1.8	0.8
Kahe (observations)			-0 30		+0.2	---		2.0	
Kahe (suggested)			0 00	0 00	+0.1	0.0	1.2	1.9	0.8

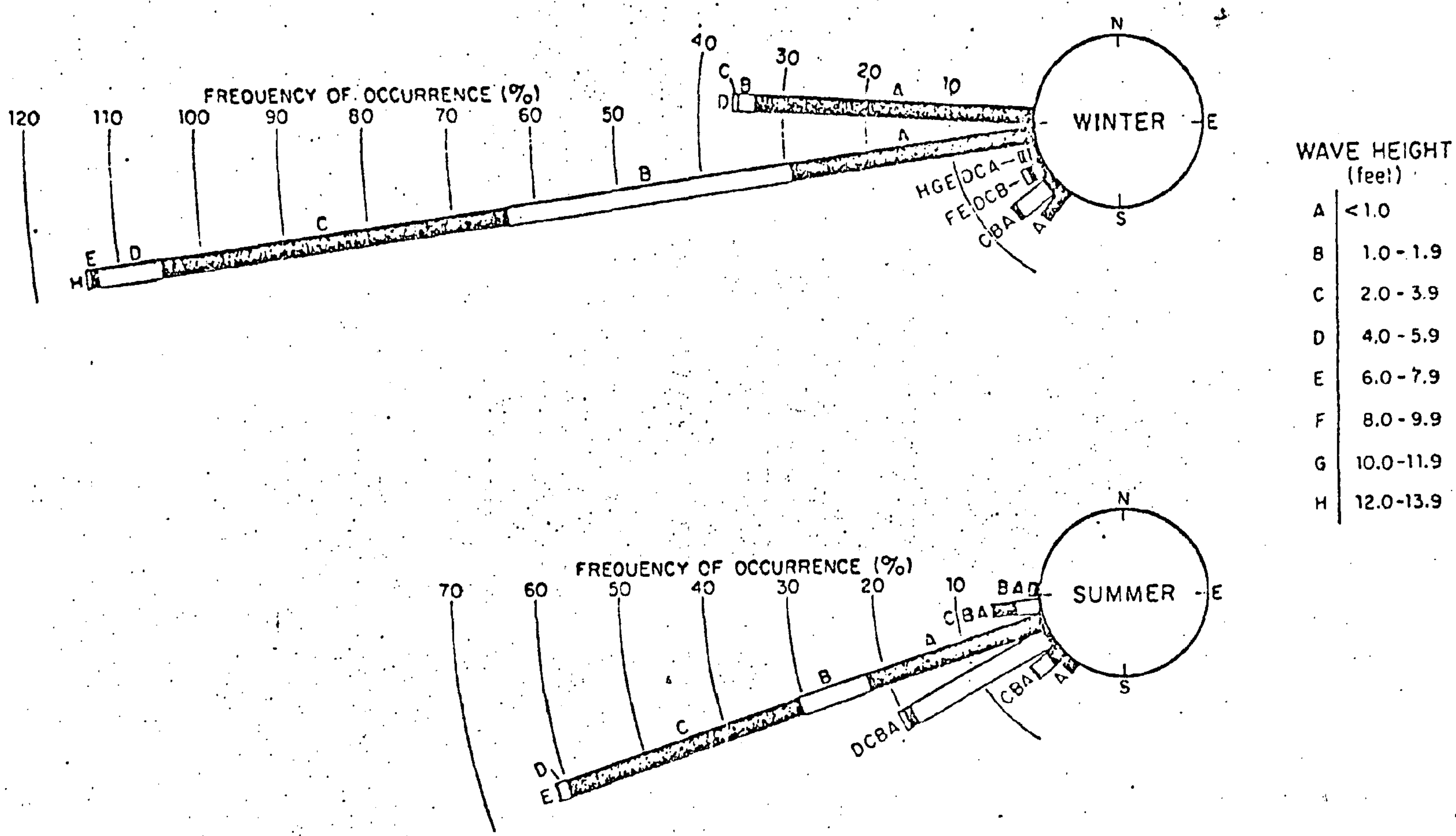


FIGURE 2. Breaking wave roses at Kahe for typical year. (Note: There is no fixed correspondence between the black-white scheme and the wave height groups. Each ray begins with black at the central circle, regardless of whether the initial height group is A, B, C, etc.; thereafter black and white alternate continuously along the ray regardless of whether all height groups are present or not. Letters along, or at the end of, the ray [redacted]

west and west-southwest prevail during the winter months, when waves reach their greatest heights. Predominant wave heights are one to three feet. During the summer, wave direction shifts to the southwest to south-southwest sector, and wave height diminishes. The predominant wave directions are responsible for longshore transport toward the north in summer and toward the south in winter (Marine Advisors, 1964).

Breaker heights of summer, tradewind-generated waves are small. Breaker heights of other wave types ("Kona" storms, North Pacific swell) are reduced at the shoreline because Ma'ili Point and Barbers Point act as wave barriers. However, the breaker line further offshore may attain heights of six feet during storm wave conditions (Marine Advisors, 1964).

Characteristics of the wave climate off Barbers Point have been studied by A.H. Glenn and Associates. Wave height frequencies from eight octants were measured for four months. These measurements and a summary of annual conditions for Barbers Point are reported in Conoco-Dillingham (1972).

General directions and characteristics of currents in the Kahe OTEC area have been summarized by Bathen (1978), using data from a variety of sources (Engineering Science, et al, 1971; Wyrtki, et al, 1967, 1969; Laevastu, et al, 1964; Bathen, 1973; Conoco-Dillingham, 1972).

Discontinuity in the available data is caused by variations in investigators' techniques and conditions under which observations were made. The general impression is that currents can be highly variable depending upon specific location or season. Currents are generally weak along the leeward coast of O'ahu, except near Barbers Point and Ka'ena Point. Variations are particularly evident at locations where the influence of bottom topography, eddies, and longshore currents become important. Off Barbers Point, velocities up to 0.8 knots have been measured and larger velocities have been reported.

From approximately 500 feet offshore of Kahe, circulation is quite uniform in velocity and depends mainly on tidal-induced currents and wave-driven ocean currents. The current component induced by tidal exchange is consistent, going to the south on a flood tide and to the north on an ebb tide (Marine Advisors, 1964).

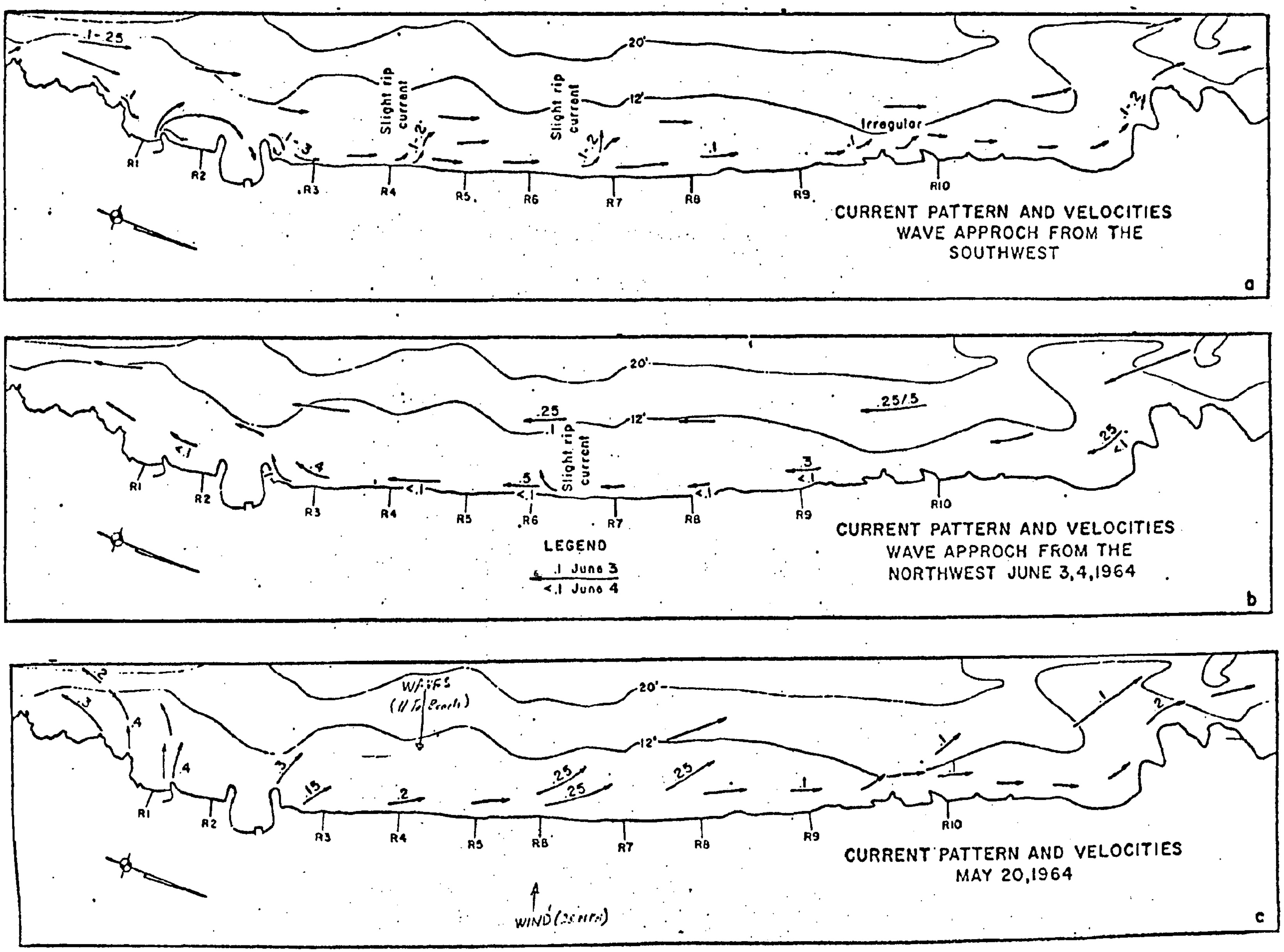
In contrast to this deepwater pattern of tidally induced currents, Leis (1978) found the opposite pattern for tidal currents within 500 feet of the Kahe shoreline. Currents on falling tides set to the south and southwest toward Barbers Point and reversed northward toward Ma'ili point with rising tide during March - September or at time of high tide during October - February. Inshore current velocities were substantially greater than offshore and were maximal during summer months (median = 1.9 knots). Opposing patterns of tidally induced currents for offshore and nearshore areas indicate an eddy system of flow reversal to be present off Kahe (Leis, 1978).

Superimposed on tidal effects on currents are the effects of wind and wave action. A shallow layer of surface water generally moves in the direction of the wind, but mass transport in the direction of propogation by waves also causes surface water motion. In the absence of strong winds, currents tend to flow generally parallel with the bottom contours (Marine Advisors, 1964).

Currents in the littoral zone at Kahe are basically related to wave action and wave approach to shore. However, the intermediate area between the littoral and deep zones can be affected by either current source or only one. At times when tidal changes are extreme and waves are slight, the water movement in the intermediate zone is induced largely by deepwater currents, but when the tidal change is small, the intermediate littoral zone is dominated by the wave regime (Marine Advisors, 1964).

The general current pattern and velocities shown in Figure 3a represent those observed under different tidal actions and when the wave approach is from the southwest quadrant. Patterns under these conditions were somewhat irregular, depending on the wave and wind conditions. When currents were slight, there were several small rip currents, where surface water flowed seaward for several hundred feet. These seaward-flowing currents are generally quite narrow (100 to 150 feet wide) but they shift laterally along the shore several hundred feet during the day. Sometimes these rip currents were also found off small protrusions from the beach and off the coolant water discharge.

Figure 3b shows the current pattern and velocities under different tidal conditions when the wave approach is from the northwest quadrant. Velocities vary greatly, from less than 0.1 to 0.5 knots, and depend upon meteorological conditions. Currents up to 0.5 knots were measured when wind gusts reached 25 mph and waves with periods of between six and eight seconds and heights of three to five feet approached from the northwest. In



[redacted] FIG[redacted] 3.[redacted] Cu[redacted]t [redacted]te[redacted] an[redacted]elo[redacted]y [redacted]he[redacted]he [redacted]a. [redacted]ari[redacted]Adv[redacted]rs[redacted]964) [redacted] contrast, when there was almost no wind and waves were only one to two feet high, currents setting southwest were less than 0.1 knot.

Figure 3c represents the currents observed when the wind was blowing offshore with gusts up to 25 mph and the wave approach seemed to be parallel with the central portion of the beach. The wave approach to the beach formed an open angle to the northwest towards HECO Beach park and an open angle to the south towards Kahe Park. The current pattern consequently was somewhat different that noted at other times; currents set northwest and offshore from the intake basin to HECO Beach Park, but currents set offshore and to the south from the basin to the Kahe Beach Park bath house (Marine Advisors, 1964).

CHEMISTRY AND BIOLOGY

The presently available oceanographic information relevant to an OTEC plant in the Kahe area has been divided into two groups. The first group has been termed "site specific"; while not necessarily specific to the actual proposed OTEC 10/40 site (roughly three miles offshore of the Kahe generating station), the site specific area has been defined as that area bounded by lines perpendicular to the shoreline at Pokai Bay and Barbers Point, and extending to 5 miles offshore. The 1000 m contour occurs roughly at this 5 mile boundary. Studies which occurred wholly or partly within this potential OTEC area are considered "site specific."

A larger body of information exists for areas outside the potential OTEC area described above. Because the offshore oceanographic realm is relatively uniform physically, chemically and biologically, these studies, while not specific to the OTEC site, are still of use in establishing baseline environmental conditions in a general sense. These studies have been termed "Hawaiian"; the majority of these studies however, have been done around O'ahu.

Site Specific Studies

The major (in fact, only) source of offshore site specific chemical and biological oceanographic information for the OTEC 10/40 potential area has been generated by a project funded by the Lawrence Berkeley Laboratory (University of California) - the O'ahu OTEC Environmental Benchmark Survey (Noda et. al., 1981). This baseline environmental study consisted of a series of six oceanographic cruises over a 1 year period from May 1980 to May 1981. Two sampling sites were visited: one site was approximately 5 miles offshore from the Kahe generating station. The other site was located approximately 5 miles offshore from Maili Point, to the north of Kahe. On each cruise, a series of three hydrocasts were made at each station collecting water samples from 13 depths between the surface and 1,000 m. Water from these samples was analyzed for dissolved nutrients (nitrate-nitrite, ammonium, phosphate, and silicate), total nitrogen, phosphorus, and carbon, dissolved oxygen, salinity, pH and alkalinity. Water samples from the upper 150 m were also used for analysis of primary productivity, plant pigment concentrations and levels of ATP (adenosine triphosphate).

Net tows for zooplankton and larval fish were taken at both stations. Surface tows were made with a surface sampling neuston net. Subsurface oblique tows covering four depth intervals (0-25, 25-200, 200-600, 600-1,000 m) were taken with an opening-closing plankton net. Zooplankton samples were analysed for species composition and abundance, and biomass (dry weight, ash-free dry weight, carbon and nitrogen).

The remaining oceanographic studies which have been done within the site specific area have been for the most part biological in nature. All have been done in the near-shore area. A series of studies centered around the Kahe generating station and extending not more than one mile offshore concentrated on the vertical and horizontal distribution of larval fish and the possible effects of the generating station on these animals (Leis, 1978; Leis and Miller, 1976; Miller, 1974; 1978). Two zooplankton studies, also related to the Kahe station and also nearshore, have been done (Environmental Consultants, 1974; Ziemann, 1977). The objective of these two studies was to determine the effects of entrainment through the Kahe station on resident zooplankton communities. Data on taxonomic composition, relative abundance, and mortality rates were generated. A study of entrainment effects on phytoplankton (Bienfang and Johnson, 1980) has also been done.

Hawaiian Studies

Because of the paucity of site-specific chemical and biological data presently available for the proposed OTEC 10/40 site of Kahe Point, and because the offshore environment of Hawaii is relatively uniform, a significant portion of the work effort in this literature review was directed at areas outside the site specific area, but within a reasonable distance (200 miles) of the Hawaiian Islands.

The study most likely to afford directly comparable data to the O'ahu OTEC Benchmark Environmental Survey is the OTEC Benchmark Environmental Survey (AECOS, 1979; Noda et.al., 1980) which occurred off the island of Hawaii during the period October 1978-December 1979. Six oceanographic cruises were taken to the site of the proposed OTEC-1 test platform, approximately 18 miles from Kawaihae Harbor. In general, four hydrocasts were taken on each cruise, two during the day and two at night. One of each of the day and night hydrocasts consisted of 12 widely spaced samples from the surface to 1000 m. The other day and night hydrocasts consisted of 12 closely spaced samples covering the interval from the surface to 300 m. Water samples from each hydrocast were analysed for dissolved nutrients (nitrate-nitrite, ammonium, phosphate, silicate, urea), total nitrogen and phosphorus, dissolved oxygen, salinity, pH and alkalinity. Water samples were also analysed for primary productivity, plant pigments, and ATP. Zooplankton tows covering several depth intervals (0-25, 25-200, 200-600, 600-1,000 m) were also taken.

A number of pertinent studies have been done off the leeward coast of O'ahu but outside the "site specific" OTEC 10/40 area. Several of these have examined the ecology of various groups of mid-water nektonic organisms. Studies of fishes include those coverings myctophids (Clarke, 1973), stomiatoids (Clarke, 1974), hatchet fishes (Ridge, in prep.) and a group of 15 families of rare to moderately abundant fishes (Clarke, 1978). Crustaceans also studied include the midwater sergestids (Walters, 1976), euphausiids (Hu, 1978) penaeids (Riggs, 1977) and carideans (Ziemann, 1975). These studies have examined the vertical distributions, patterns of vertical migrations and life histories of these widely diverse groups of organisms. Additional studies which were concerned with the structure of the micronektonic fish communities (Amesbury, 1975), feeding patterns of micronektonic fishes (Clarke and Wagner, 1976), and the whole micronektonic community off O'ahu (Maynard et.al., 1975) have also been done.

Studies which were done even further offshore, but which are still applicable to the Kahe OTEC region, have included surveys of the chemistry, phytoplankton, microzooplankton, bacteria and fungi in the photic zone (Gundersen et. al., 1976), the chemistry and microbiology of several leeward Hawaiian locations (Gundersen et. al., 1972), the temporal variability of primary productivity at a station north of O'ahu (Cattell and Gordon, 1971; Muller, 1971), and the distribution of particulate carbon and nitrogen at the same station (Gordon, 1970; 1971). Other studies have described the changes in primary productivity which occur as the distance from an oceanic island changes (Doty and Ogori, 1956; Gilmartin and Revelate, 1974). A resource-oriented study which examined the hydrography, distribution of plankton stocks, levels of primary productivity, and potential fishery yields in the epipelagic zone in the Hawaiian Islands between Midway Island and the island of Hawaii found strong uniformity and low variability in the parameters measured over the whole extent of the Hawaiian chain (Hirota et. al., 1980). Relatively specialized studies examining phytoplankton sinking rates (Bienfang, 1980) and the effects of light on primary production (Bienfang and Gundersen, 1977) also have been done.

The water column offshore of the Hawaiian Islands is relatively constant in structure and may be divided into three layers: a warm, shallow, variable depth mixed layer in which nutrient concentrations are low and where the majority of the biological activity occurs; a cold, deep layer where nutrient concentrations are high and biological activity is relatively low; and an intermediate gradient layer where changes in temperature (from warm to cold) and nutrinet concentration (from low to high) occur wih increasing depth.

The depth of the mixed layer varies with and is dependent on the amount of insolation and the degree of wind mixing. Generally the mixed layer reaches its maxinmum depth (100 m) in summer and is shallowest (50 m) in winter. Due to the active uptake of nutrients by the phytoplankton and the slow rate of regeneration and renewal by diffusion from below, the nutrient levels in the mixed layer are low, often reaching non-detectable levels for some chemical species. The majority of the plankton biomass occurs in this layer and the upper 50 to 100 m of the intermediate layer below. The maximum levels of chlorophyll generally occur between 90 and 120 m, while the maxima for ATP and productivity occur at depths of 50 m and less.

Zooplankton biomass is greatest in the upper 25 m, and decreases with depth. Numerically the copepods are the most abundant group of zooplankton. Larval fish are relatively low in abundance in offshore waters.

The deep layer (below 400 m) is characterized by low temperatures, little or no light during the day, relatively high nutrient levels due to the bacteriological breakdown of organic material from the upper layer, and relatively uniform conditions. The major biological groups of fishes, crustaceans, and cephalopods generally all undergo extensive diurnal vertial migrations, moving upward to shallower depths at night.

PART 3: LITERATURE REVIEW RELEVANT TO THE IMPACTS OF OTEC DEVELOPMENT

This section discusses the potential environmental impacts on marine communities and fisheries effects associated with the deployment of an OTEC (Ocean Thermal Energy Conversion) plant of four designs in the waters offshore of Kahe Point, Oahu, Hawaii. The four alternative designs are: (1) the offshore vessel design (which would be similar to the successful Mini-OTEC and OTEC-1 where the vessel is emplaced over the deep, cold water that is pumped to the surface); (2) the onshore OTEC station (similar to the Keahole Point Facility) where the deep, cold water is pumped via pipe to shore, is used and discarded; (3) the derrick configuration where a derrick supporting the OTEC plant is deployed in waters about 90 m in depth and the cold water is pumped to the plant via pipe, used and discharged nearby; and (4) the mobile OTEC plant which is similar to the first design but is not tied to any single geographical locality. The mobile OTEC would have the capability to move across the central and western Pacific centered on the belt of warm equatorial waters in search of appropriate thermal conditions for the ultimate production of portable energy such as liquid hydrogen or ammonia.

Each of these alternative designs would have a variety of impacts on the marine communities in which they operate. This document will consider the impacts on the macrobiota of these marine communities, that is, in coastal ecosystems, the fish, corals and other larger invertebrates, and in the offshore realm, the larger pelagic fish species. Due to the large number of unanswered questions in this undertaking (e.g., unknown physical characteristics and behavior of the cold water discharge in an unknown current system, volume of the thermal effluent, the unknown effects of cold water on tropical inshore and pelagic marine species), the impacts (both positive and negative) noted below could be enhanced or totally negated depending on temporal and spatial conditions. Thus, the portrayal of these impacts is subject to re-evaluation as data become available.

The impacts associated with each of these alternative designs are discussed below.

OFFSHORE VESSEL AND MOBILE OTEC ALTERNATIVES

As stated above, these OTEC designs would be similar to either OTEC-1 or Mini-OTEC, where the vessel is held on station and the deep, cold water is pumped via a pipe to the surface where it is used in developing an energy source. The cold water is then passed overboard. In the offshore vessel design, electricity would be generated and in this scenario, passed via cables to shore (here Kahe Point). In the mobile OTEC alternative the vesel would not be tied to a particular geographical locality but could move about seeking the appropriate site in the belt of warm equatorial waters. A number of the impacts associated with either of these designs would be analogous, thus they are discussed together.

Impacts

An extensive and efficient searching operation is usually necessary to locate and harvest migratory tunas in the central and western Pacific. However, tunas and other pelagic fishes are known to congregate around floating objects in the ocean. Increased catches are frequently made by commercial and sport fishermen around such flotsam (Gooding and Magnuson, 1967; Hunter and Mitchell, 1967, 1968; Greenblatt, 1979; Murdy, 1980). Several theories have been suggested to explain the aggregating effects of flotsam. However, no single hypothesis can completely explain such associations. The presence of small fishes which find shelter in the floating debris may attract and hold larger predatory fishes (Gooding and Magnuson, 1967; Mitchell and Hunter, 1970; Wickham, et. al., 1973). Pelagic fishes may gather around floating objects because these structures can provide spatial references for individual orientation in an otherwise unstructured pelagic environment (Klima and Wickham, 1971). In less than one month from the time of emplacement of a floating object, the population of large fishes increases to a maximum and thereafter fluctuates with the arrival and departure of individuals and schools (Hunter and Mitchell, 1968; Murdy, 1980).

Floating objects in Hawaiian waters are capable of aggregating fishes of economic importance. In 1977-1978, the National Marine Fisheries Service Honolulu Laboratory deployed a series of experimental anchored buoys in Hawaiian waters which proved successful in aggregating economically valuable fish. Commercial pole-and-line vessels caught a large percentage of their total skipjack tuna landings around the experimental buoys. Although the average catch rate of buoy-associated pole-and-line fishing (2,140 kg per vessel trip) was similar to the average catch rate from normal school-searching operations (2,000 kg per vessel trip), the aggregation system provided the following advantages:

(a) Fish schools attracted to the buoys remained at the buoy site for several days and often as long as two weeks.

(b) The buoys reduced the time lost scouting for tuna schools, thus reducing fuel and operating expenses.

(c) Successful fishing trips were made to buoy sites even with inferior baitfish species and with baitfish in weakened condition.

(d) Less bait than would normally be used for fishing free swimming schools was required around buoys. Therefore, vessels were able to make more fishing trips per week.

(e) Many boats which were accustomed to remaining in port during the winter months were enticed to fish more often because of the presence of the buoys (PTDF, 1979).

Trolling and hand-line fishing developed around the buoys in addition to commercial skipjack fishing efforts.

The immediate success of the buoys and the demand for additional systems prompted the development of a statewide system of 26 fish aggregation devices (or FADs) by the Hawaii Division of Fish and Game. The FAD's were deployed in spring 1980 between 4.8 and 40 km offshore and were anchored in waters as deep as 1.8 km. Commercial and sport fisheries catches during the first year of the program were monitored through the use of a voluntary report card system. In addition a joint research program was initiated by the University of Hawaii Sea Grant Program, the State of Hawaii Marine Affairs Coordinator, NMFS, and the State Division of Fish and Game to document the establishment, growth, and continuity of fish populations associated with the buoys.

The Hawaii fish aggregation devices are physically small (1.8 m or 6 feet across), yet may attract large quantities of commercially valuable fish. Buoy performance varies both in time and space but aggregation devices anchored in deeper waters (between 0.9 km and 1.8 km) produce significantly greater catches than do their shallower counterparts. FAD's were purposely deployed in a pattern that will allow comparisons of how differences in bottom depth, profile, and oceanographic conditions affect fish abundance hence fishing success. In practice, however, buoy positions represented a compromise between project interests, local politics, and restrictions imposed by the U.S. Coast Guard and Navy to reduce hazards to surface navigation and submarine traffic.

In the first year of the Hawaii FAD program, commercial pole-and-line vessels harvested an estimated 364 metric tons of skipjack and other tuna in approximately 180 fishing trips to 9 of the aggregation devices. About 65% of the total pole-and-line tuna catch came from the vicinity of one buoy. This buoy yielded over 227 metric tons of surface tuna. If this tonnage is representative of a productive buoy, the annual resource potential of a well-positioned aggregation device (such as an offshore OTEC vessel) may be on the order of 227 metric tons.

About 80% of the skipjack fish effort was expended at 4 buoys, where average catch rates ranged between 820 and 3,730 kg per trip. Pole-and-line fishing in the vicinity of FAD's yielded about 2 metric tons per trip. At cannery prices ($1.10/kg), each fishing trip of this type produced gross revenues of $2,200.

A commercial handline fishery has expanded and developed around the fish aggregation devices which were deployed off the Kona coast of the Island of Hawai'i. This fishery is conducted using small boats and a minimal amount of fishing gear. The target species are large, deep-swimming yellowfin tuna (_Thunnus albacares_) and bigeye tuna (_T. obesus_), which command high prices in the fresh (raw fish or sashimi) fish market in both Hawai'i and abroad. The fish aggregation devices have provided an opportunity to substantially expand the traditional Kona handline fishery. The number of boats has increased from 30-40 to about 120. The total Island of Hawai'i catch of high value tunas reported in 1980 was approximately 318 metric tons but under-reporting is prevalent and actual production is probably much more, perhaps as much as 1800 metric tons. Total annual revenues from this industry may be as much as $10 million.

Catch data from several Kona-based tuna handline fishermen who use the buoys extensively were analyzed for this study. Catches of their target species, large yellowfin and bigeye tuna, averaged between 29 and 120 kg per trip for individual fishermen (mean = 61 kg/trip). Under-reporting of these catches is a common occurrence as noted above because of the large revenues accrued by commercial handline fishermen. The actual catches of buoy-associated large tuna are believed to range between 90 and 320 kg per fishing trip. The fishermen reported a combined catch of over 3.6 metric tons in a one-month period from the vicinity of one FAD. This figure may be low by a factor of three. If Kona handline catches provide an indication of the full resource potential of a single FAD, annual landings of high-value tuna may approach 4,550-136,360 kg per device.

In addition to the commercial baitboat and handline fisheries, an additional 20,000 kg of fish caught in the vicinity of the Hawai'i FAD's during the first year of operation were sold for an estimated $137,000. Six of the bouys received about 70% of the fishing effort. Mahimahi accounted for approximately 40% (by weight) of the total catch. Marlin and skipjack tuna followed in abundance. Table 2 summarizes the estimated weight and wholesale value of commercial landings around the FAD's, excluding the commercial baitboat and handline activities.

Table 2. Estimated weight and wholesale value of other commercial fish landings (excluding baitboat and handline fisheries) near Hawai'i fish aggregation devices during first year of operation.

Species	Weight (kg)	Wholesale Value per #(1)	Wholesale Value total
Mahimahi	17,050	$2.17	$81,000
Marlin	11,500	0.80	20,000
Skipjack tuna	8,000	1.08	19,000
Ono	1,730	2.09	8,000
Kawakawa	550	0.89	1,000
Opelu	500	1.27	1,000
Miscellaneous	2,400	1.36	7,000
Total	41,820		$137,000

(1) Based on average of January - June 1980 ex-vessel price reported by Hawaii Division of Fish and Game.

The deployment of an OTEC platform results in aggregation of commercially-valuable fish in the same manner as a buoy or any other floating object. The aggregation effect is enhanced by the larger submerged surface of an offshore OTEC vessel. Observations made from the OTEC-1 vessel when in operation suggested that commercial handline fishing activity conducted in the vicinity of the device was highly productive. On the average, about 10 small boats per day were observed carrying out fishing activities around OTEC-1 over a 75-day period (D. Crear, pers. comm.).

Catches were yellowfin and bigeye tuna having an ex-vessel (wholesale) value ranging from $3 to over $5 per pound. Catches of large, high-value tunas averaged about 230 kg per vessel fishing trip to OTEC-1 (J. Kinney, pers. comm.). The small-boat tuna handline fleet probably caught a total of 2.3 metric tons per day of fishing. Assuming a wholesale (ex-vessel) value of at least $3.00/lb, the Kona handline fishery generated gross revenues of at least $15,000 per day as a direct result of the OTEC-1 project.

Non-commercial sport fishermen also benefit from the Hawaii FAD system and can be expected to receive similar recreational benefits from deployment of an offshore OTEC vessel. In the first year of the Hawaii FAD project, charter-fishermen and recreational trollers caught an estimated 21 metric tons of yellowfin tuna, 14 metric tons of mahimahi (<u>Coryphaena hippurus</u>), and 12.7 metric tons of marlin in over 1,000 fishing trips. Sport fishermen also caught more than 6 metric tons of skipjack tuna (<u>Katsuwonus pelamis</u>), and other pelagic species. Catch per trip averaged 21 kg of yellowfin tuna, 13 kg of mahimahi, 12 kg of marlin, and 6 kg of skipjack and other species. Five buoys received about 65% of the fishing effort and produced 60% of the total catch. Average catch rates varied from 23 kg per trip to 86 kg per trip at the most popular buoys.

The rapidly-changing status of worldwide oil supplies will force continual updating and reassessment of the fossil fuel requirements and energy costs of fisheries. Escalating fuel prices will cause previously acceptable fishing methods and technologies to be no longer attractive and will force adoption of fuel-conserving fishing methods. Energy concerns will ultimately result in fisheries development programs which combine the goals of increased catch and fuel conservation, rather than seeking to maximize yields at any cost of energy (Bardach, 1979).

Standard trolling and school-searching operations are costly in terms of fuel consumption. FAD-associated fishing is rapidly gaining recognition as a more economical alternative method of harvesting. Buoys not only aggregate fish, but they also allow fishermen to locate fishery resources without wasting time, fuel, and money. Offshore OTEC vessels have major implications for energy conservation in harvesting pelagic fisheries resources. Thus the deployment of an OTEC structure offshore of Kahe Point, Oahu would be expected to aggregate commercially valuable fish for potential harvest. This aggregation process would commence at the time of deployment and the usual assemblage of species and biomass of fish would be present within 2 to 5 weeks from that time.

A mobile OTEC device could be expected to magnify the fish aggregation effects that drifting logs are known to have in the equatorial waters of the western Pacific, hence such a platform would likewise function in the same fashion as do the FAD's or permanently stationary OTEC devices. Fishing activities around a mobile OTEC platform could follow the methods employed in the vicinity of the Hawaiian FADs or use longline and purse seine techniques.

Purse seining is the least labor and most capital intensive of the tuna fishing methods. However, it is less fuel-efficient than other commercial tuna fishing methods. Combining the harvesting efficiency of purse seining with the fuel-efficiency of utilizing fish aggregation devices would represent a major opportunity for fisheries development in the central and western Pacific.

The Pacific Tuna Development Foundation began exploratory surveys in 1976 in an effort to expand the United States purse seine fishery to the central and western Pacific Ocean (Anon, 1976). To date, surface tuna availability and vulnerability to purse seine gear have been surveyed in a series of 7 charters. After many years of exploratory fishing, Japanese fishing interests now consider purse seine operations in the western Pacific to be commercially feasible and are adding larger and more sophisticated vessels to the present fleet of 15 vessels (Anon, 1977). Experience of U.S. and Japanese tuna seiners has established that surface tuna schools in the western Pacific exhibit wild and erratic behavior and are difficult to capture using purse seine gear. Fish behavior, coupled with the deep thermocline and clear water of the central and western Pacific Ocean, lowers the vulnerability of surface schools to existing purse seine technology (Salomons and Souter, 1980).

The most successful method of purse seining tuna in the western Pacific has been pre-dawn sets on tuna aggregated beneath or close to drifting logs, which currents tend to concentrate in certain areas of the western Pacific. Pre-dawn "log" sets accounted for the major portion of the catch by PTDF purse seine charters until the 1979-1980 Island Princess cruises. For the past 14 years, Japanese seiners operating in the equatorial waters of the western Pacific have concentrated their efforts almost entirely on log sets begun before sunrise. Japanese seiners catch about 11 metric tons per fishing day using this technique. U. S. seiners average 8 metric tons per day when they concentrate on early morning sets around floating logs (Anon, 1976). Catches as large as 100 metric tons per day have been made using these techniques in Papua New Guinea waters.

Purse seining combined with moored floating objects began and has evolved into a highly productive fishery in the Philippines. Rafts are made of oil drums and bamboo, are 10 to 15 m in length, and are set 30 to 60 km offshore. They attract tuna (skipjack and yellowfin) which are caught using a modern purse seining techniques (Bardach and Matsuda, 1980). Rafts are usually deployed and left for 3 to 4 weeks. Catches may range up to 35 metric tons per set (Murdy, 1980) and harvesting may occur every 5 to 6 days (Bardach and Matsuda, 1980) but normally once every 3 weeks (Murdy, 1980). About one-half of the catch is comprised of fish less than 1 kg in body weight, a small size for skipjack, which constitute about 60% of the landings. Yellowfin contribute about 25 percent to the purse seine catches and bigeye tuna, about 15 percent (Bardach and Matsuda, 1980).

It is generally well known in the tropical Pacific that rafts or FADs provide an efficient means of aggregating tuna for harvest. These devices have been deployed in the Trust Territory, the western Pacific (Philippines, Papua New Guinea) and scattered eastward to the Hawaiian Islands. Both Japanese and American fishing interests have deployed fish aggregating devices on the high seas for their own use. Fiji has recently begun an ambitious fisheries program with the deployment of 60 FADs in their waters. In most localities where they have not broken free of their moorings, these FADs have efficiently aggregated fish for harvest, and their popularity has continued to grow.

Moored floating objects serve to attract small and medium sized tuna (0.5 to 10 kg) in almost every locality that they have been deployed. Efficient harvest techniques such as purse seining coupled with the aggregation powers of a FAD or a Philippine raft could pose a threat to tuna stocks by the overexploitation of small fish that have not participated in the spawning process. These juvenile fish will aggregate around an OTEC platform (moored or mobile) and if they are similarly subjected to overfishing, a decline in the landings of the larger fish could result.

Data from the Japanese longline fishery for yellowfin tuna, covering nearly the entire range of the species, indicate that an increase in fishing intensity would damage the stock and depress total yield. After an initial increase in yield, yellowfin catches have reached a plateau from which they have not risen despite increasing fishing effort. Therefore, yellowfin are considered fully exploited as far as longline fisheries are concerned, with some additional potential, perhaps, in the central Pacific sub-population where the fish caught are larger, on the average, than those taken in the western and eastern Pacific (Suzuki, et. al., 1978; Bardach and Matsuda, 1980).

Skipjack tuna catches, on the other hand, have generally risen with increasing fishing pressure, although there are large fluctuations from year to year which appeared to be linked to variations in oceanographic and meteorological conditions. Skipjack represent the largest underexploited fishery resource of the central Pacific. Potential additional yield from the Pacific is believed to be in excess of 100,000 metric tons (Hester and Broadhead, 1980).

Purse seining in the vicinity of an OTEC platform would be analogous to log associated purse seining practiced by the U.S. and Japanese purse seiners in the western Pacific or to the raft fishing in the Philippines. Three U.S. purse seiners are currently operating in the western Pacific. These vessels plus 6 other super-seiners (1,000-2,000 + GT class) participate in the seasonal purse seine fishery for skipjack tuna off New Zealand. Recent Japanese success with purse seining in the equatorial waters of the western Pacific offers encouragement for additional U.S. seiners to extend operations. There are approximately 130 purse seiners under U.S. flag, of which 95 are capable of extended trips to the central and western Pacific (Anon, 1979).

With problems in gaining access to and maintaining previous levels of catch in the traditional eastern Pacific tuna fishing grounds, between 25 and 50 U.S. purse seine vessels might be expected to divert activities to a central and western Pacific fishery (Broadhead, 1976). Thus, with our advancing technology of FADs and OTEC structures serving to aggregate tons of tuna coupled with modern purse seiners for their capture, the probability of sustained yeilds will be reduced without appropriate international management of this resource.

A major negative impact from either a moored or mobile OTEC is created by the cold water effluent. The effects of relatively cold water impinging on tropical shallow water marine forms has received little scrutiny in the scientific literature; nor have such studies been carried out on pelagic organisms. It is known that tunas have rather narrow thermal tolerances and are able to thermo-regulate (Dizon and Brill, 1979). Yellowfin tuna are fished in waters with surface temperatures between 23° to 32°C (Sharp, 1978) and skipjack between 19° to 23°C (Laevastu and Rosa, 1963). Skipjack however, are found in waters with a surface temperature range between 17° to 28°C (Laevastu and Rosa, 1963).

The effects of a cold water OTEC effluent on tunas aggregating about such a platform would be dependent upon the volume of effluent, its temperature differential relative to the surface waters, and the rapidity with which it mixes with the warmer receiving waters. The latter is strongly influenced by the strength of the surface water movement and hence by the wind.

If a thermal situation similar to that at OTEC-1 were to exist near the proposed platform, then there would probably be little influence on the aggregating fish. In the case of OTEC-1, the cold water effluent was approximately 18°C (65° F; D. Crear, pers. comm.) which is close to the lower limit of preferred skipjack temperatures and 1°C below the lower limit of yellowfin temperatures. At OTEC-1, fish (yellowfin primarily) apparently swam through the surface-released effluent with impunity. The effluent was probably very rapidly mixed, hence its effects were dissipated within meters of the point source. Thus it is probable in offshore waters that such a cold water effluent on relatively small scale would have little impact on sub-adult and adult fish. Likewise, with this rapid dilution and dissipation, the negative effects on the thermally more susceptible larvae of these important marine fish would probably be negligible.

Presumably with the offshore vessel alternative, there would be some means of transmitting the electricity from the platform to shore. This transmission would probably be via undersea cable. The laying of a cable through shallow marine communities adjacent to shore could have a number of impacts. These overlap with impacts that would be created by use of the derrick configuration and will be discussed below.

DERRICK ALTERNATIVE

In this design, a permanent OTEC plant would be placed on a derrick platform (similar to an oil rig) in waters about 90 m in depth. The plant would draw the cold deep water by pipe from somewhere seaward of the platform, generate electricity, discharge the cold water effluent adjacent to the derrick and transmit the end product (electricity) to shore via cable.

Assuming an emplacement along the 90 m isobath, the platform would be about 1.8 km from shore at Kahe Point, O'ahu. A derrick situated in waters of these depths may serve to aggregate fish, but probably not the more pelagic, commercially important tunas, etc. Fishes attracted to such a structure would most likely be more benthic in nature; the most economically important might be the lutjanids or snappers.

Substratum is an important parameter governing the structure, diversity and density of organisms in any shallow benthic community. Areas of considerable structural relief (habitat heterogeneity) will harbor a more diverse and greater standing crop of fishes and invertebrates than relatively featureless bottoms (Brock, 1954; McVey, 1971; Risk, 1972; Brock et. al., 1979). Generally in shallow waters corals are a major structural element of this third dimension. The emplacement of vertical legs reaching the seafloor and supporting the OTEC platform would add considerably to the third dimension, thus attracting fish. Platforms in shallower (20-35 m) Gulf of Mexico waters serve to attract numerous fish (Hastings et. al., 1976). Additionally, thehabitat complexity created by the cold water pipe coming from greater depths and the transmission cables running shoreward from the platform would probably enhance its fish attracting qualities. Artificial structures are usually well marked and readily accessible, so they are easily relocated using modern electronic gear and may be more susceptible to over-fishing than natural bottoms. Fisheries associated with artificial structures are subject to the same ecological constraints as those associated with natural bottoms of complex relief.

The species composition and abundance of the fish community resulting from structure emplacement off Kahe Point is a matter of conjecture. No data exist for artificial structures placed in Hawaiian waters at similar depths. In the Gulf of Mexico, Hastings et. al., (1976) found 101 species of fishes distributed between two structures; Klima and Wickham (1971) reported that small midwater structures attracted up to 25 metric tons of fish in the same areas. In all probability the fish community developing around the Hawaiian platform would be a mix of coral reef species, more pelagic wandering species (jacks, etc.) and some of the deeper benthic forms (snappers: uku, opakapaka, etc).

The deployment of the deep, coldwater intake pipe and the electrical transmission cables could create a number of negative impacts. If dredging or blasting has to be undertaken for the laying of these lines, a large amount of silt could be produced. This silt and detritus could have a negative influence on nearby benthic communities.

The shallow benthic communities of the Kahe-Barber's Point region are known to be diverse. These communities have received considerable attention in the environmental literature due to the presence of the Hawaiian Electric Company generating facility at Kahe Point. Many of these studies have recorded more than 100 species of fishes occurring in waters less than 20 m in depth. This has been documented at Kahe by URS Research Co. (1972, 1973), McCain and Peck (1973), Coles and McCain (1973-more than 180 species), and Hawaiian Electric Co. (1976), to the south by Kimmerer and Durbin (1975), and offshore of the Barge Harbor by Environmental Consultants, Inc. (1975). Apparently, these varied fish populations are a relatively continuous element along the coast and are related to the diverse coral communities in the area. In the most recent survey, Bienfang and Brock (1980) semi-quantitatively inventoried the benthic communities found between Kahe and Barber's Point. They noted more than 100 species of fishes and more than 50 percent of the known Hawaiian coral species were recorded in their survey.

Silt and detritus serve to cut down the transmission of light through the water column, thus decreasing productivity. In its extreme, silt can cause the smoothering or burial of sessile benthic organisms. If currents do not carry this particulate material out of these benthic communities, it can effectively bury the hard substratum that serves as the foundation on which coral communities are built. In general, the impact of the construction activities associated with emplacement of the derrick platform on surrounding benthic communities would be dependent on the amount of silt generated as well as the strength of currents at the time.

Other negative impacts associated with the derrick alternative center around the cold water effluent. The negative effects of such an effluent would be largely dependent on the temperature of the impinging effluent, its mixing, and on the local current systems. If cold water from the OTEC plant is carried shoreward, it could affect the diverse coral communities of the Kahe Point region. These impacts will be discussed further under the shore based OTEC alternative.

The cold water discharge, if not rapidly mixed, could form a thermal barrier to successful recruitment of numerous species. In most marine organisms, larval forms are more susceptible to fluxes in physical parameters and many tropical marine species (both fishes and invertebrates) have larval phases that are planktonic and spend some time in the offshore pelagic realm. If a cell of cold water discharged from the derrick were to lie offshore but paralleling shore, it might hamper larval recruitment to the shoreward communities. If continued through time, the result might be a localized change in species composition in the affected nearshore benthic communities.

The cold water effluent could have a negative effect on fishes attempting to aggregate around the derrick's underwater structure. If the thermal regime were inappropriate, fishes would probably avoid the affected area. However, all of these scenarios and presumed negative effects depend on the volume of the cold water effluent, location of discharge, its temperature differential below ambient, and the strength and direction of advective currents.

ONSHORE ALTERNATIVE

This proposed alternative would place an OTEC plant on the Kahe Point shoreline. Cold water used in the facility would be brought from the depths via a pipe laid on the bottom to the plant; this pipe would probably extend seaward for about 2 km. The cold water would be used in the OTEC process, mixed, and discharged back into the ocean in the vicinity of the plant. All of the negative effects created by this method of electrical generation have been discussed under the other alternatives; however, the impact of these on nearshore benthic communities would probably be greatest under this plan.

Studies conducted on the effects of temperature on Hawaiian reef corals suggests that a decrease in the natural water temperature would be more harmful to corals than a temperature increase of the same magnitude (Jokiel and Coles, 1977). These authors established a lower lethal limit of 18°C for a number of Hawaiian corals; the discharge of OTEC-1 was about 18°C. Other than this study, the effects of relatively cold water impinging on tropical marine forms has received little attention in the scientific literature. Heated effluents, on the other hand, being a product of oil fired electrical generators, have been studied by biologists working on coral reefs (for example, see: Coles, 1973, 1975, 1980; Coles and McCain, 1973; Coles and Fukuda, 1975; Coles, et.al., 1976; Clausen and Roth, 1975; Grovhoug, 1978; Jokiel and Coles, 1974; Jokiel and Guinther, 1978; Marsh and Doty, 1975, 1976; Marsh et.al., 1977; McCain, 1977; Neudecker, 1976, 1977; Roessler and Zieman, 1969).

With no dominating advective forces, cold water discharged into warmer receiving waters will sink (due to density differences). In the coral reef system a discharge of cold water would mix with the receiving waters but also would probably sink to the bottom where damage to corals and other sessile biota could occur. With sufficient discharge and time, the magnitude of this impact on the coral reefs off Kahe Point could be great. Under these altered circumstances, motile biota would be expected to change.

The placement of the intake pipe for the shoreside facility could create a number of negative impacts to the shallow benthic communities which it traverses. Again, dredging associated with pipe deployment could create high water column particulate levels thus imposing a negative influence on adjacent coral communities.

Although data are not available on how much sedimentation Hawaiian reef corals can withstand under either acute conditions or prolonged deposition, corals are capable of surviving in locations where the rate of sediment deposition is less than the rate of sediment removal by agents such as secretion of mucus, movement of cilia, extension of polyps, water currents, gravity, and/or fish grazing. Death of coral tissue from sedimentation is believed to result from smothering or oxygen depletion in the anoxic environment which develops beneath the sediment surface. Burial under 2 to 3 cm (1 inch) of sand for more than 48 hours is likely to cause death by suffocation (Hubbard and Pocock, 1972; Hubbard, 1974). The detrimental effects of sediment deposition appear to be most serious when the rate is extremely rapid, such as might occur during or after heavy seas.

Although most species of coral can survive a veneer (a few mm) of sediment - even when sedimentation is prolonged - most cannot live for long if heavily coated or completely buried (Johannes, 1975). Certain resistant species are able to endure smothering for short periods when completely buried by sediment, whereas other less tolerant species die quickly when covered.

New surfaces of the pipe and those created by construction activities may serve as a source for the development of ciguateric food chains, and the presence of a large diameter pipe crossing through the diverse coral communities of the Kahe Point region may not be aesthetically pleasing to users of the area.

POTENTIAL FOR CIGUATERA

Ciguatera is a form of fish poisoning caused by ingesting a wide variety of fishes (snappers, groupers, jacks, barracudas, surgeonfishes and wrasses) whose tissues contain a paralytic neurotoxin. Recently, the widely distributed, tropical dinoflagellate, Gambierdiscus toxicus (Adachi and Fukuyo), has been implicated as the source of ciguatoxin in the Pacific (Yasumoto, et. al., 1977; Yasumoto, Nakajima, Oshima, and Bagnis, 1979). This microscopic, unicellular alga grows primarily as an epiphyte on certain brown and red seaweeds on reef flats with population densities varying greatly over short distances (Yasumoto, Inoue, Bagnis, and Gercon, 1979). There are several other epiphytic dinoflagellates which produce effects similar to ciguatoxin. Once the toxins of other species accumulate in the food chain, they become difficult to differentiate from the effects of G. toxicus (Yasumoto, 1979).

Blooms of the dinoflagellate apparently initiate the process of transfer of toxic material through the food chain. The environmental conditions which trigger massive blooms of the dinoflagellate are not known, although conditions which have been repeatedly associated with ciguatera are dredging of reef areas, sunken ships, and rainfall-runoff patterns.

Incidences of ciguatera poisoning in Hawai'i have frequently been connected with construction activities which have exposed new submerged surfaces through dredging. A small bloom of G. toxicus occurred at Pokai Bay in August 1978, coincident with dredging of a small boat harbor nearby and with an outbreak of ciguatera in fish from that area (Withers, et. al., 1980).

The potential does exist for an increase in toxicity of edible fishes residing in waters around the site of marine construction. The on-shore alternative for construction of an OTEC facility at Kahe may involve considerable dredging in shallow waters. The red alga, *Jania* sp., which is commonly colonized by *G. toxicus* (Yasumoto, 1979) is relatively common in the nearshore area. To date, no one can predict whether or not a given construction activity in the marine environment will lead to incidences of ciguatera.

CURRENT STATUS OF FISHERIES

The area bounded by Ma'ili Point and Barbers Point and extending offshore to a distance of 20 miles produces average annual commercial fish landings of between 50,000 and 75,000 lbs, excluding skipjack tuna. Skipjack tuna catch within this region averages between 250,000 and 500,000 lbs per year. Inshore areas between Kane'ilio Point and Kahe Point are heavily fished, but fishing pressure drops off markedly south of Kahe Point to Barbers Point. The only site in the latter area where fishing is concentrated is the Campbell Barge harbor. At least 4,000 of O'ahu's population of resident fishermen frequent inshore areas of the Kahe OTEC region at one time or another. Pole fishing is the primary activity, although spearing, lay netting, and handlining (from boats) are common near shore. Aquarium fish collecting is a major commercial activity at depths between 30 and 60 feet. Commercial trapping of Kona crabs takes place on sand bottoms at depths between 50 and 300 feet. The distribution of recreational and commercial fishing uses is mapped in a generalized form in Figure 4.

Shorefishing in the area between Kahe Point and Kane'ilio

FIGURE 4

Key to Fishing Uses

A. NETTING	1. Lay netting 2. Crabbing 3. Throw netting 4. Bait collecting 5. Aquarium fish collecting
B. HOOK AND LINE	1. Shorecasting 2. Hand pole and line 3. Bottom handlining 4. Trolling
C. SPEARING	1. Diving 2. Torchfishing 3. Squidding
D. TRAPPING	
E. GATHERING	1. 'Opihi 2. Limu 3. Wana 4. Lobster 5. Shell collecting 6. Miscellaneous (coral heads, other)

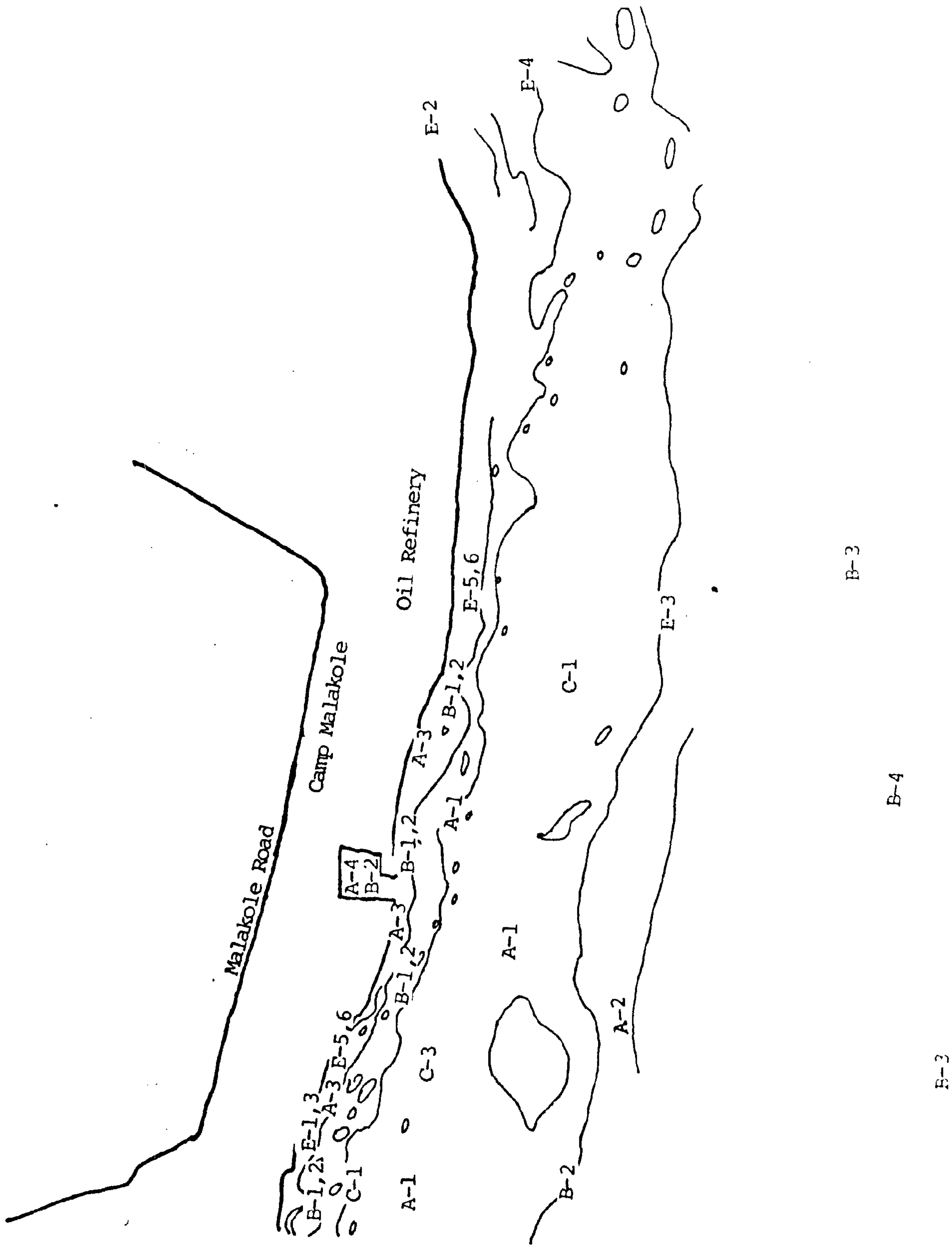


Figure 4. The distribution of recreational and commercial fishing uses in the Kahe OTEC area.

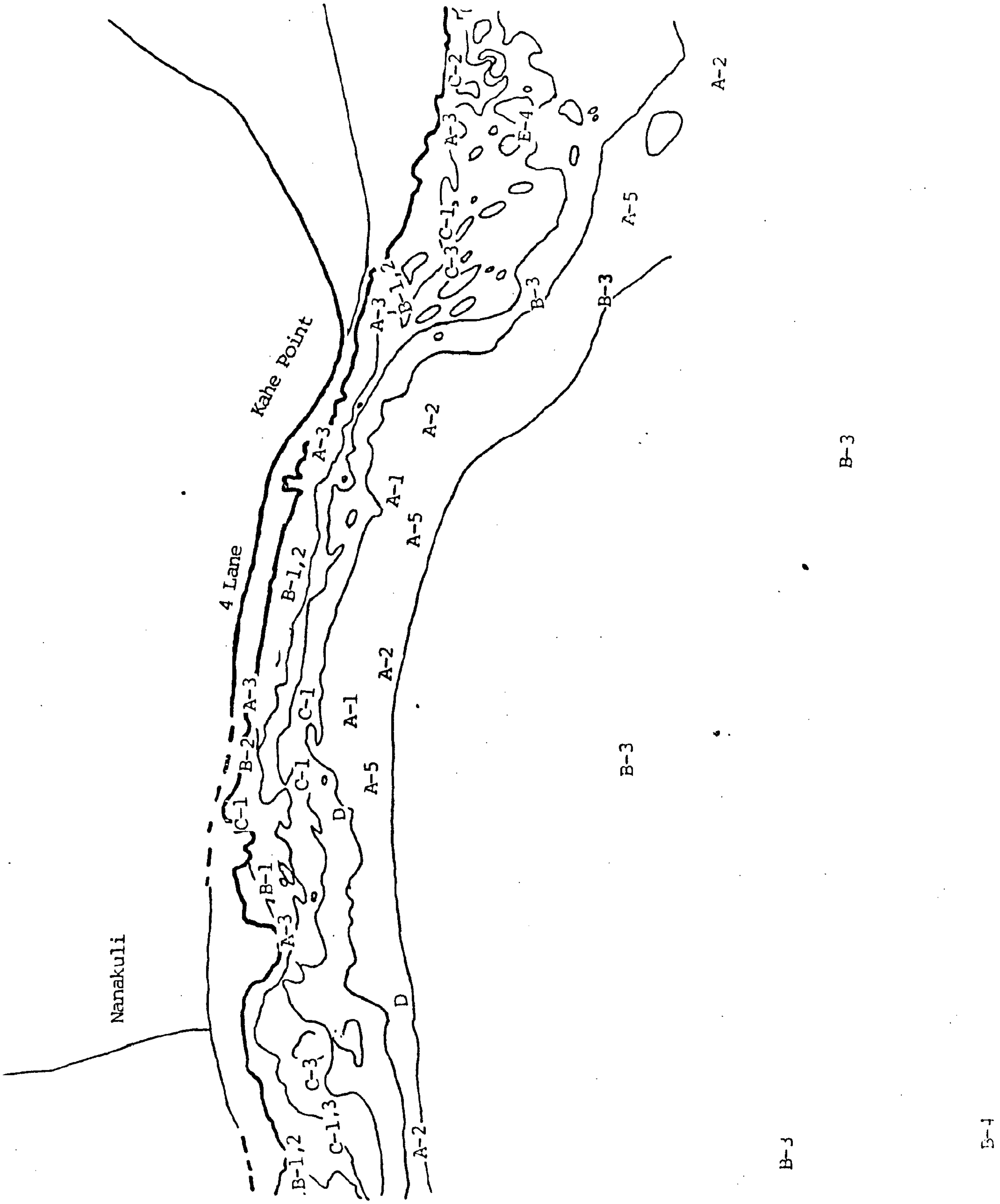


Figure 4. The distribution of recreational and commercial fishing uses in the Kahe OTEC area.

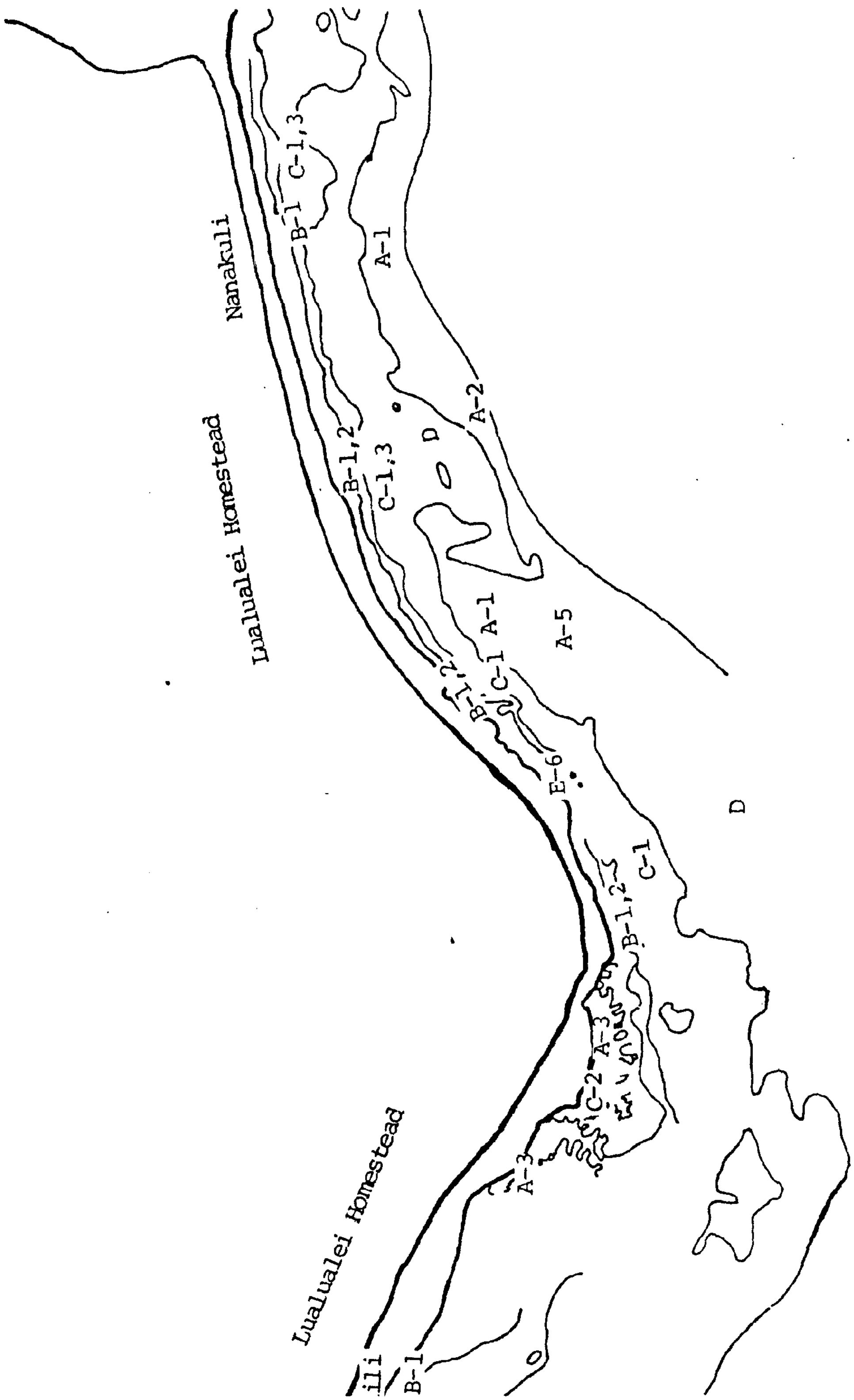


Figure 4. The distribution of recreational and commercial fishing uses in the Kahe OTEC area.

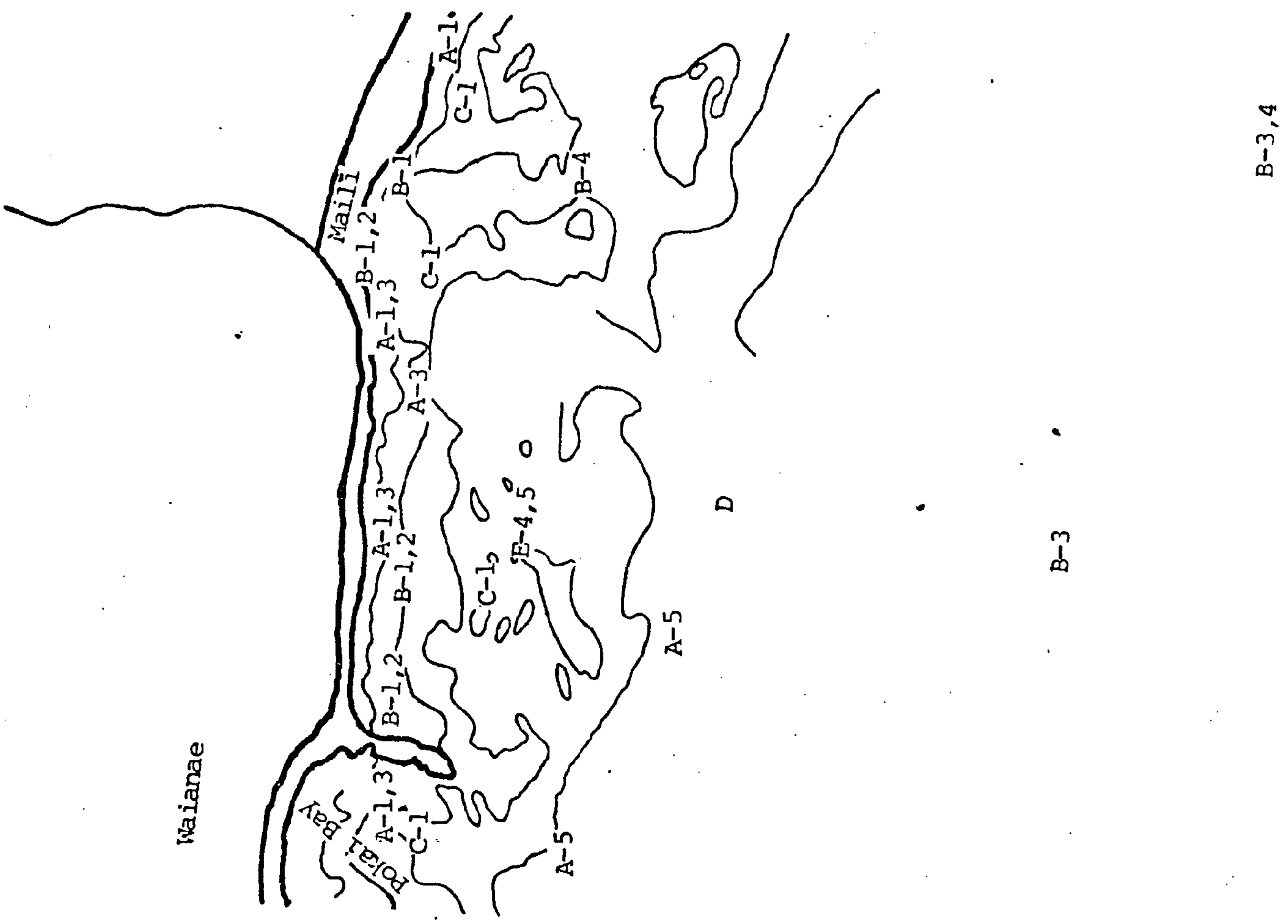


Figure 4. The distribution of recreational and commercial fishing uses in the Kahe OTEC area.

Point yields a relatively low catch per hour of effort (0.3 lb/hr). Pole-and-line fishing is somewhat more productive south of Kahe Point (0.4 lb/hr) and much more productive north of the Kahe region (0.9 lb/hr). Net fishing results in highly variable catches, averaging 1 to 5 lb/hr throughout the inshore area. Spearing typically yields about 0.9 pounds per hour of fishing effort in the nearshore area of the Kahe OTEC region and tends to be less productive north of the Kahe region (0.5 lb/hr). The seasonal pole-and-line fishery for o'ama which is conducted during the late summer periods of juvenile goatfish abundance produces catches of 0.7 to 0.8 pounds per fishing day between Campbell Barge Harbor and Ma'ili Point, but only half that (0.3 to 0.4 pounds per day) between Ma'ili Point and Kane'ilio Point. Fishes of high commercial value which are relatively common in the Kahe region are 'u'u, uouoa, aholehole, aweoweo, akule, 'opelu, uku, papio, and weke. The scientific and local names of these species, general habitat, and usual methods of capture are summarized in Table 3. Overall, the shoreline and inshore areas north of Poka'i Bay provide more successful fishing (in terms of catch per hour of fishing) than the study area itself. This is reflected in larger numbers of recreational fishermen and larger recreational catches in the Poka'i area.

The section of coast between "West Beach" (Lanikuhonua) and Barbers Point receives relatively little fishing pressure in comparison to the coast north of Kahe Beach Park. Fishing activity in the nearshore area is estimated to be about 10 hours per sq km per day (Bienfang and Brock, 1980). Portions of the nearshore area (to depths of 60 feet) are known to harbor populations

Table 3. Relatively common fishes of high commercial value found in the Kahe OTEC region.

FAMILY	SCIENTIFIC NAME	LOCAL NAME	GENERAL HABITAT	USUAL METHODS OF CAPTURE
Squirrel-fishes	*Myripristis* sp.	'u'u (menpachi)	Surge zone; sub-surge zone	Spear, hook and line, trap
Mugilidae	*Neomyxus chaptalii*	uouoa	Surge zone	Throw net
Kuhliidae	*Kuhlia sandvicensis*	aholehole	Surge zone	Throw net, hook and line, spear
Priacanthidae	*Priacanthus cruenatus*	aweoweo	Surge zone	Hook and line, spear
Jacks	*Caranx* sp.	papio	Surge zone; sub-surge zone	Hook and line
	Decapterus macarellus	'opelu	Sub-surge zone	Hook and line, lift net
	Selar crumenophthalmus		Sub-surge zone	Surround net hook and line (juveniles)
Snappers	*Aprion virescens*	uku	Sub-surge zone	Hook and line
Goatfishes	*Mulloidichthyes flavolineatus*	weke 'a'a	Surge zone	Net, spear, hook and line (juveniles)
	M. vanicolensis	weke 'ula	Sub-surge zone	Net, spear, hook and line
	Parupeneus porphyreus	kumu	Surge zone	Spear, trap

Source: AECOS, Inc. 1980. Oahu Coral Reef Inventory, Island of Oahu.

of commercially valuable spiny lobsters or 'ula (*Panulirus penicillatus*). Octopus or he'e (*Octopus cyanea*) are taken by spear and the traditional cowrie shell lure technique.

The abundance of commercially valuable fish species in the nearshore region fronting West Beach and the Campbell Industrial Park was much greater ten years ago than at present. Species such as u'u, aweoweo, and aholehole were common, as were lobsters. At greater depths offshore, uku was previously more common. Development of the Campbell Industrial Park improved accessability and led to increased fishing effort, which has presumably reduced the stocks of desirable species (Bienfang and Brock, 1980).

Inshore waters in the general vicinity of Barbers Point are known among fishermen as harboring an abundance of juveniles of many species of commercial interest.

The primary recreational fishery in offshore waters is trolling, which is conducted primarily on weekends by vessels ranging from 14 to 35 feet in length. Off Kahe, trapping of Kona crabs is a significant fishery over sand bottoms at depths between 50 and 300 feet. Akule are netted in offshore waters by commercial fishermen. Commercial pole-and-line vessels harvest skipjack tuna at greater distances (20 nautical miles) offshore. Average annual commercial landings of various species in the inshore and offshore waters of the Kahe OTEC region are tabulated in Table 4.

Recreational trolling blends recreational, subsistence, and commercial purposes for fishing. Catch per unit effort is so

Table 4. Catch by species (in pounds) from commercial fisheries in the Kahe OTEC region.

F I S H

Local/Common Name	Scientific Name	Catch Per Season (lbs.) Jan.-June	July-Dec.
Aku (Skipjack Tuna)	*Katsuwonus pelamis*	128,110	178,080
Ahi (Yellowfin Tuna)	*Thunnus albacares*	10,460	19,175
Akule (Bigeye Scad)	*Selar crumenophthalmus*	9,354	5,350
A'u (Black Marlin)	*Makaira indica*	3,494	7,280
Hahalu (Juvenile Bigeye Scad)	*Selar crumenophthalmus*	2,283	4,905
Mahimahi (Dolphinfish)	*Coryphaena hippurus*	3,673	2,947
A'u ki (Striped Marlin)	*Tetrapturus audax*	2,564	3,221
A'u (Blue Marlin)	*Makaira nigricans*	2,096	2,710
Ta'ape (Blue-Lined Snapper)	*Lutjanus kasmira*	1,370	1,931
'O'Io (Bonefish)	*Albula vulpes*	1,416	731
Weke (Yellowstripe Goatfish)	*Mulloidichthys flavolineatus*	1,179	1,639
Weke'ula (Red Goatfish)	*Mulloidichthys vanicolensis*	789	1,401
"Opelu (Mackeral Scad)	*Decapterus macarellus*	336	1,375
Ulua (Jack)	*Caranx* spp.	1,298	871
Kawakawa (Little Tuna)	*Euthynnus yaito*	445	1,364
Ono (Wahoo)	*Acanthocybium solandri*	948	932
Kala (Unicorn Surgeonfish)	*Naso unicornis*	540	769
Palani (Surgeonfish)	*Acanthurus dussumieri*	389	645
Menpachi (Squirrelfish)	*Myripristis* sp.	262	560
Kumu (White-Spot Goatfish)	*Parupeneus porphyreus*	431	281
A'u (Shortbill Spearfish)	*Tetrapturus angustirostris*	426	89
Awa (Milkfish)	*Chanos chanos*	357	198
Mamo (Sargeant Major)	*Abudefduf abdominalis*	257	206
Ahi (Bigeye Tuna)	*Thunnus obesus*	36	233
Kahala (Amberjack)	*Seriola dumerilii*	220	59
'Opakapaka (Snapper)	*Pristimoides filamentosus*	156	238
Pualu (Ringtailed Surgeonfish)	*Acanthurus xanthopterus*	177	58
'Omilu (Blue Jack)	*Caranx melampygus*	54	144
Uhu (Parrotfish)	*Scarus* spp.	125	59

I N V E R T E B R A T E S

Local/Common Name	Scientific Name	Catch Per Season (lbs.) Jan.-June	July-Dec.
Ula (Spiny Lobster)	*Panulirus* spp.	161	113
He'e (Octopus)	*Octopus* spp.	99	381

L I M U

Local/Common Name	Scientific Name	Catch Per Season (lbs.) Jan.-June	July-Dec.
Limu (Seaweeds)	All species	1,472	913

Source: Hawaii Division of Fish and Game Catch Statistics for Area 402 (Inshore) and Area 422 (Offshore).

variable and the area trolled is usually so large that it is difficult to segregate the Kahe OTEC region from the rest of leeward O'ahu. The primary target species are yellowfin tuna (ahi) and blue marlin, but various other billfish are also taken.

Recreational trolling is concentrated between Kahe Point and Ma'ili Point, the latter site being a traditional area of concentration. On summer weekends when ocean conditions are favorable, it is not uncommon for 50 to 100 recreational trawlers to operate in the northern portion of the Kahe OTEC region. Recreational trolling declines considerably south of the Kahe-Brown's Camp area as rougher waters (caused by the "point effect" of Barbers Point) are encountered. At one time or another, at least 300 sport fishing vessels fish in the Kahe OTEC region.

The second most important recreational fishery practiced from small boats in the Kahe region is night handlining for menpachi at shallow depths (30 feet). Because dark nights produce the highest catches of this nocturnal feeder, fishing activity is limited, on the average, to two weekends per month when the phase of the moon is suitable. Decreasing abundance of menpachi off Kahe has caused a decline in total catch and fishing effort of this type in recent years. Table 5 summarizes the catches of menpachi and associated species which were made between 1974 and 1980 by one recreational fisherman who is active in the night handline fishery. Although catch per month and per year declined after 1975, recent (1980) fishing has been nearly as productive as earlier years. In general, the highest catches were made during the July - September period.

The major Kona storm of January 1980 moved large quantities

Table 5. Catch of menpachi and associated species (lbs) by one recreational handline fisherman, Kahe OTEC region, 1974 - 1980.

MONTH	1974	1975	1976	1977	1978	1979	1980
January	-	1	15	-	-	-	-
February	140	-	30	15	-	-	-
March	45	-	100	50	-	-	70
April	52	-	30	80	75	-	165
May	178	130	80 (8)	-	-	-	70 (10)
June	-	30	20	35	30	-	-
July	-	180 (10)	100	100 (8)	-	-	-
August	230	290	90 (3)	-	155	-	-
September	210	35	40	155	50	50	325
October	5 (16)	45 (10)	-	-	50	60	90
November	78 (7)	-	80 (10)	-	85	-	-
December	35	-	-	-	-	-	-
Total Annual	973 (22)	711 (20)	585 (21)	935 (8)	455	110	720 (10)

Note: Figures in ( ) indicate catches of associated species.

Source: AECOS, Inc. Personal communication with licensed commercial fisherman, name withheld on request, June 1981 of sand into shallow waters, covering areas of hard bottom. This change in bottom habitat is reflected in a marked increase in menpachi and other sand bottom feeders noted by spearfishermen who have used the Kahe area for years.

The major environmental factors which recreational fishermen identify as affecting fisheries resource availability or fishing success in the Kahe OTEC area are summarized in Table 6.

Table 6. Environmental factors known or believed to influence fisheries resource availability or fishing success in the Kahe OTEC region.

FACTOR	EFFECT
Season	'oama - usually run between July and September akule (hahalu) - usually reach peak abundance in the period March through May. menpachi - most abundant in the period July through September tunas and other offshore species - most abundant in the period May through September.
Tide (moon phase)	Inshore fishery improves during full moon or new moon phases associated with large tidal exchange. Fishing for akule, 'opelu, menpachi is best on dark nights. Trolling is most productive 7 to 10 days following a full moon. Inshore fishing improves with a rising tide. Tide phase is apparently not important in the offshore trolling fishery.
Water turbulence	The availability of nocturnal feeding fishes (red fish, akule, 'opelu) is greatest during calm conditions and light winds. Water turbulence stirs up bottom sediments. Increased turbidity apparently interfers with feeding by species which eat small invertebrates inhabiting sand bottoms (menpachi).
Water temperature	Offshore surface tuna fisheries improve with warmer ocean temperatres.
Runoff	No major drainage channels enter the ocean off the southern portion of the Kahe OTEC region. However, the remnant of an old stream bed between Kahe Beach park and Brown's Camp discharges turbid water after heavy rainfall. High turbidity reduces inshore catches to virtually nothing.
Biological interaction	Fishermen are concerned that the introduced snapper or ta'ape (*Lutjanus kasmira*) is displacing popular food fish, particularly weke (*Mulloidichthys* spp.).

APPENDIX B

Kahe OTEC Larval Fish Survey

Prepared by AECOS, Inc. for Parsons Hawaii

August 1981

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INTRODUCTION

Operation of an OTEC facility in a nearshore marine environment has the potential for negative impacts on the planktonic biota of the area due to entrainment through the plant and thermal effects resulting from the discharge of water which is below ambient temperature as the result of mixing warm surface water with cold deep water. In areas where fish of commercial importance are known to reproduce, the operation of an OTEC plant has the potential for negative impacts on an important commercial resource. In order to assess the impact of proposed OTEC facility operations in the waters off Kahe Point, Oahu, Hawaii, it is necessary to have some estimate of the species composition and abundance of the larval fish in the area. In order to generate this information, a series of samples were taken with surface and sub-surface plankton nets to generate species lists and estimates of larval fish abundances in the proposed OTEC operating region.

METHODS

Plankton tows designed to sample the larval fish in the surface waters off Kahe Point, Oahu, were made on 27 July and 27 August, 1981. Triplicate tows were made at each of three locations: 1.5, 3.0, and 5.0 miles offshore from the Hawaiian Electric Company Kahe Point generating station. All tows were made during the morning and early afternoon, in directions parallel to the shoreline, and at speed of 1.5 to 2 knots.

Two types of tows were made at each station. Oblique tows were made with a 1 m diameter, 500 u mesh net fitted with a General Oceanics digital flowmeter. Oblique tows which sampled between the surface and 50 m were made by lowering the net at 5 m increments while the boat was underway. The net remained at each depth increment for 1 minute. After the net had sampled the last depth increment, the boat was slowed and the net was rapidly retrieved with an electric line hauler. Total tow duration was approximately fifteen minutes.

Surface tows were made with a specially designed neuston net. The net consisted of a standard 1 m diameter, 500 u mesh plankton net attached to a special surface sampling frame. The frame was rectangular, 1 m x 0.5 m on a side. Float/skis were mounted halfway along the 0.5 m sides, so the lower 25 cm of the frame was below the water surface and the upper 25 cm was above the surface. A General Oceanics digital flowmeter was located at approximately 12 cm below the water surface. The neuston net was towed for 10 minutes for each sample.

At the end of each sample tow, the zooplankton sample was removed from the cod end of the net, placed in a 1 quart glass jar, preserved with a 5% formalin-sea water solution, and returned to the laboratory for analysis. In the lab, all larval fish were removed from the samples, identified under a dissecting microscope (to species where possible), and enumerated. The volume filtered was calculated from the flow meter data for each sample, and this data was used to convert the numbers of larval fish per sample to numbers per standard volume (1000 m^3).

RESULTS

The results of the larval fish sampling program are presented in the following tables. At each station data are listed by net type and replicate number. The total number of larval fish (# per 1000 m^3), the number of specimens actually found in each sample, the number of species in each sample, the volume of water filtered in taking the sample, and the volume correction factor $\underline{x}$ (where 1 individual per sample = $\underline{x}$ per 1000 m^3) are also presented.

TABLE B-1

Larval Fish Abundance
Station 1 - July 1981

SITE: KAHE/OTEC STATION: 1 DATE: July 27, 1981

TOW TYPE		NEUSTON			OBLIQUE		
Replicate		1	2	3	1	2	3
Family: Species							
Apogonidae:	*Apogon* sp.						20.2
	Epigonus occidentalis					27.3	
	Foa brachygramma				18.2		
	unid.						10.1
Atherinidae:	*Pranesus insularum*	18.3	67.1	84.5			
Blenniidae:	*Enchelyurus brunneolus*	30.5	6.1	52.0	91.0	56.7	20.2
	Plagiotremus sp.						10.1
Chiasmodontidae:	*Pseudocopelus* sp.				9.1		
Coryphaenidae:	*Coryphaena hippurus*				9.1		
Exocoetidae:		6.1					
Gobiidae:	*Bathygobius fuscus*				9.1	8.1	
	Eviota epiphanes				109.2	24.3	
	Asterropteryx semipunctatus					8.1	
Gonostomatidae:	*Cyclothone* sp.				45.5	40.5	
Hemiramphidae:	sp. 1			6.5			
Myctophidae:	*Benthosema* sp. unid.				9.1		
	Bolinichthys sp.					8.1	
	Ceratoscopelus warmingi				9.1		10.1
	Diaphus spp.				27.3	8.1	
	Diaphus pacificus (?)				9.1		
Pomacentridae:	*Abudefduf abdominalis*				27.3	48.6	20.2
	S. fasciolatus					8.1	
	P-5				9.1		
	Damaged				9.1		
Scombridae:	*Thunnus albacares*					8.1	
	Unid. <3.5mm				18.2	8.1	
Unidentified					9.1		
Yolk Sac					9.1		
Unidentified damaged						8.1	
TOTAL		54.9	73.2	143.0	427.7	262.2	90.9
Individuals		9	12	22	51	29	9
Species		3	2	3	18	12	6
Volume Filtered (M^3)		165	163	153	110	124	99
Volume Factor (1 per sample = X per 1,000 m^3)		6.1	6.1	6.5	9.1	8.1	10.1

TABLE B-2

Larval Fish Abundance
Station 2 - July 1981

SITE: KAHE/OTEC · STATION: 2 DATE: July 27, 1981

TOW TYPE		NEUSTON			OBLIQUE		
Replicate		1	2	3	1	2	3
Family: Species							
Apogonidae:	*Apogon* sp.				3.6	4.8	4.9
	Epigonus occidentalis					9.6	4.9
Atherinidae:	*Pranesus insularum*	18.3	4.9	18.9			
Blenniidae:	*Enchelyurus brunneolus*	6.1			3.6		4.9
Carangidae:	Unid.				3.6		4.9
Exocoetidae:		24.4	29.4	44.1	3.6		4.9
Gonostomatidae:	*Cyclothone* sp.				25.2	24.0	44.1
Hemiramphidae:	sp. 1	6.1		233.1	3.6	19.2	
Myctophidae:	*Ceratoscopelus warmingi*				3.6		
	Diaphus spp.				3.6	4.8	14.7
	Lampadena sp.				3.6		9.8
Nomeidae:	*Cubiceps pauciradiatus*					4.8	
	Cubiceps caeruleus		4.9				
Pomacentridae:	*Abudefduf abdominalis*				13.2		
	Abudefduf sordidus (jun)			6.3			
Scombridae:	*Thunnus* sp.				3.6		9.8
	Unid.					4.8	
	Thunnus albacares				3.6		
Tetradontidae:					3.6		
Damaged					13.2		4.9
Yolk Sac		6.1					
K3 (Hemiramphidae sp. 2)			4.9	6.3			
TOTAL		61.0	44.1	308.7	91.2	72.0	107.8
Individuals		10	9	49	21	15	22
Species		5	4	5	14	7	10
Volume Filtered (M^3)		163	203	158	280	209	206
Volume Factor (1 per sample = X per 1,000 m^3)		6.1	4.9	6.3	3.6	4.8	4.9

TABLE B-3

Larval Fish Abundance
Station 3 - July 1981

SITE: KAHE/OTEC · STATION: 3 DATE: July 27, 1981

TOW TYPE		NEUSTON			OBLIQUE		
Replicate		1	2	3	1	2	3
Family: Species							
Apogonidae:	*Apogon* sp.				6.6		
	Epigonus occidentalis				3.3		3.5
Blenniidae:	*Exallias brevis*						3.5
Carangidae	*Seriola* sp.				3.3		
	Selar crumenophthalmus					3.6	
Chlorophthalmidae:	*Chlorophthalmus proridens*				3.3		
Coryphaenidae:	*Coryphaena hippurus*					3.6	
Exocoetidae:		51.3	67.1	69.6			
Gonostomatidae:	*Cyclothone* sp.				56.1	100.8	98.0
	Diplophos taenia				3.3	7.2	
Hemiramphidae:	sp. 1				23.1		
Itiophoridae:	*Itiophorus angustirostris*						3.5
Melanocoetidae:	*Melanocoetus johnsoni*				3.3		
Myctophidae:	Unid.						7.0
	Bolinichthys sp.				6.6		7.0
	Ceratoscopelus warmingi				3.3	18.0	3.5
	Diaphus spp.				33.0	25.2	56.0
	Lampadena sp.				6.6		3.5
	Triphoturus nigrescens					3.6	
Nomeidae:	*Cubiceps pauciradiatus*						7.0
Pomacentridae:	*Abudefduf abdominalis*				3.3		
Scombridae:	*Thunnus* sp.				13.2	5.0	7.0
	Unid.						3.5
	Thunnus albacares				6.6		
	Katsuwonus Pelamis					3.6	7.0
Damaged			6.1		3.3		3.5
Yolk Sac						3.6	3.5
K1					3.3		38.5
Unid.					9.9	7.2	3.5
K2		5.7	12.2	11.6			
K3 (Hemiramphidae sp. 2)			12.2	23.2			
TOTAL		57.0	97.6	104.4	188.1	181.4	259.0
Individuals		10	16	18	58	54	64
Species		2	4	3	18	11	18
Volume Filtered (M^3)		175	164	174	299	278	290
Volume Factor (1 per sample = X per 1,000 m^3)		5.7	6.1	5.8	3.3	3.6	3.5

TABLE B-4

Larval Fish Abundance
Station 1 - August 1981

SITE: KAHE/OTEC · STATION: 1 DATE: August 27, 1981

TOW TYPE		NEUSTON			OBLIQUE		
Replicate		1	2	3	1	2	3
Family: Species							
Apogonidae:	*Epigonus occidentalis*				10.4		
Atherinidae:	*Pranesus insularum*	67.1	64.9	84.0			
Blenniidae:	*Enchelyurus brunneolus*	6.1			10.4		
Carangidae:	*Selar crumenophthalmus*				10.4	8.1	
	<1.5 mm					16.2	
Chiasmodontidae:							7.9
Coryphaenidae:	*Coryphaena hippurus*						7.9
Exocoetidae:			17.7	49.0			
Gobiidae:	*Eviota epiphanes*				31.2	8.1	7.9
	Asterropteryx Semipunctatus				10.4		
Gonostomatidae:	*Cyclothone* sp.				10.4	8.1	
	Diplophos taenia					8.1	
Hemiramphidae:	sp. 1		5.9	7.0			
Myctophidae:	*Diaphus* spp.				20.8		
	Triphoturus nigrescens					8.1	
	Damaged					8.1	
Pomacentridae:	*Abudefduf abdominalis*						7.9
Scombridae:	*Euthynnus affinis*				10.4		
	Katsuwonus pelamis						7.9
	Aconthocybium solandn					8.1	
Unidentified leptocephalus					10.4		
Unidentified		6.1			20.8		23.7
Unidentified #38					10.4		
Damaged		12.2		7.0		8.1	
K6 (Hemiramphidae sp. 3)		24.4	5.9	21.0			
K3 (Hemiramphidae sp. 2)		6.1	5.9				
TOTAL		122.0	100.3	168.0	156.0	81.0	63.2
Individuals		20	17	24	15	11	8
Species		6	5	5	11	10	6
Volume Filtered (M^3)		164	171	142	96	124	127
Volume Factor (1 per sample = X per 1,000 m^3)		6.1	5.9	7.0	10.4	8.1	7.9

TABLE B-5

Larval Fish Abundance
Station 2 - August 1981

SITE: KAHE/OTEC | STATION: 2 | DATE: August 27, 1981

TOW TYPE		NEUSTON			OBLIQUE		
Replicate		1	2	3	1	2	3
Family: Species							
Apogonidae:	*Epigonus occidentalis*				13.6	14.2	6.8
Atherinidae:	*Pranesus insularum*	97.2	29.8	95.0		7.1	
Blenniidae:	*Enchelyurus brunneolus*	13.9					
Carangidae:	*Selar crumenophthalmus*				20.4	14.2	
	Unid.				6.8	14.2	6.8
Chlorophthalmidae:	*Chlorophthalmus proridens*				13.6		
Coryphaenidae:	*Coryphaena hippurus*						6.8
Exocoetidae:		229.0	285.6	170.9	13.6	14.2	6.8
Gobiidae:	*Eviota epiphanes*				6.8	21.3	
	Gobiidae (K7)				13.6	14.2	13.6
Gonostomatidae:	*Cyclothone* sp.				20.4	56.8	
Holocentridae:					6.8		
Mullidae:							6.8
Myctophidae:	*Bolinichthys* sp.					7.1	
	Ceratoscopelus warmingi				6.8		
	Diaphus spp.				20.4	7.1	6.8
	Lampadena sp.				34.0	14.2	
Nomeidae:	*C. parciradiatus*				6.8		
Pomacentridae:	*Abudefduf abdominalis*					7.1	
	<3 mm				13.6		
Scombridae:	*Auxis* sp.				6.8		
	T. albacares						6.8
	Katsuwonus pelamis					7.1	
Tetraodontidae:						7.1	6.8
Damaged		6.9				14.2	
Unidentified						7.1	
K6 (Hemiramphidae sp. 3)			5.9	12.7			
K3 (Hemiramphidae sp. 2)			5.9				
TOTAL		347.0	327.2	278.6	204.0	234.3	68.0
Individuals		50	55	44	31	32	10
Species		4	4	5	15	16	9
Volume Filtered (M^3)		144	168	158	147	141	147
Volume Factor (1 per sample = X per 1,000 m^3)		6.94	5.95	6.33	6.80	7.09	6.80

TABLE B-6

Larval Fish Abundance
Station 3 - August 1981

SITE: KAHE/OTEC · STATION: 3 · DATE: August 27, 1981

TOW TYPE Replicate		NEUSTON 1	2	3	OBLIQUE 1	2	3
Family: Species							
Acanthuridae:					24.4	10.1	5.21
Apogonidae:	*Epigonus occidentalis*				32.5	60.6	15.6
	Unid.				16.3		
Atherinidae:	*Pranesus insularum*	50.0	41.9	74.6			
Carangidae:	*Selar crumenophthalmus*				24.4	10.1	
	Decapterus sp.				24.4		
	Unid.					20.2	5.2
Carapidae:	*Carapus* sp.				8.13		
Exocoetidae:		75.0	83.9	22.4			
Eel:	Unid. leptocephalus				8.13		5.2
Gobiidae:	*Eviota epiphanes*				32.5	10.2	5.2
	K7						10.4
Gonostomatidae:	*Cyclothone* sp.				105.7	111.1	41.6
	Vinciguerria nimbaria					10.1	
Hemiramphidae:	sp. 3			29.8			
Mullidae:					8.13	10.1	10.4
Myctophidae:	*Ceratoscopelus warmingi*					20.2	5.2
	Diaphus spp.				73.2	30.3	31.2
	Triphoturus nigrescens				8.13		
Nomeidae:	*C. parciradiatus*						5.2
Pomacentridae:	*Abudefduf abdominalis*					10.1	5.2
	Pomacentrus jenkinsi				8.13		
	Unid.				8.13	10.1	
Scombridae:	*Auxis* sp.					10.1	
	T. obesus					10.1	10.4
	Thunnus albacares					10.1	
Serranidae:					8.13		
Stomiatoid:						40.4	10.4
Tetraodontidae:	*Crystallodytes cookei*					20.2	5.2
Unidentified					8.13	10.1	36.4
Unidentified #1					8.13		
Unidentified #6							10.4
K2				7.46			
K3				7.46			
TOTAL		125.0	125.8	141.7	406.5	414.2	218.8
Individuals		15	21	19	51	42	42
Species		2	2	5	18	19	17
Volume Filtered (M^3)		120	167	134	123	99	192
Volume Factor (1 per sample = X per 1,000 m^3)		8.33	5.99	7.46	8.13	10.10	5.21

DISCUSSION

In general, there was very little overlap in species caught between the surface neuston tows and the oblique tows. The common surface-caught larvae belonged to the families Atherinidae (*Pranesus insularum*, 'iao), Blenniidae (blennies), Gobiidae (gobies), Exocoetidae (flying fish), and Hemiramphidae (half beak), none of which are of direct economic importance. The large variations in numbers caught in successive replicate tows, between the three stations, and on the two dates attest to the great variability in space and time of the distributions of these larvae.

The oblique tows caught many more species than the surface tows. While the maximum number of species present in any surface tow was six, the oblique tows usually contained more that ten species, and on several occasions as many as eighteen species. Many of these species were either mesopelagic (Myctophidae, Melanostomiatidae, Gonostomatidae) or common reef species (Apogonidae). The larvae of the species of direct commercial importance (Carangidae - jacks; Scombridae - tuna) generally were most abundant at the offshore station, and while the numbers of scombrids did not change significantly between the two sampling dates, the number of carangids caught increased by a factor of ten between July and August samplings. Mean abundances (and standard deviations of the means) for the Carangidae and Scombridae at each station for the two sampling dates are presented below.

Table 7. Larval fish abundance per 1000 m^3 (mean $\pm$ 1 standard deviation)

Station	Scombridae		Carangidae	
	7/27	8/27	7/27	8/27
1	11.5 ± 8.2	8.8 ± 1.13	0	11.6 ± 9.9
2	7.3 ± 2.0	9.3 ± 6.6	2.8 ± 2.1	20.8 ± 9.9
3	15.3 ± 4.8	13.6 ± 12.6	2.3 ± 1.6	28.1 ± 17.8

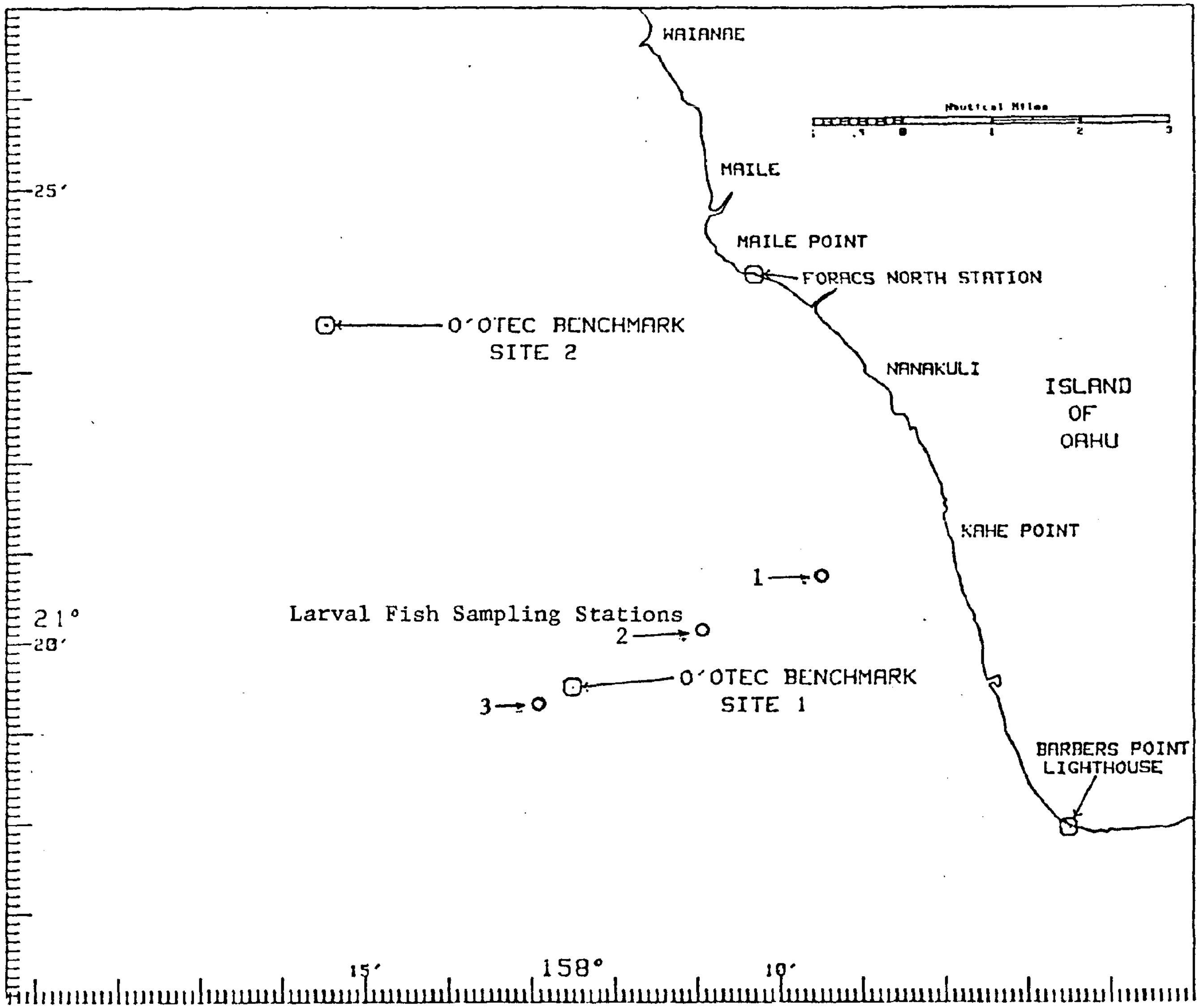

Figure B-1. Location of larval fish sampling stations and O'OTEC Benchmark Site locations (Noda, et al., 1982).

APPENDIX C

Ocean Thermal Energy Conversion (OTEC) Offshore Impacts, Their Mitigation and Regulation

Prepared by D. L. Callies for Parsons Hawaii

August 1981

MEMORANDUM

TO: Parsons Hawaii

FROM: David L. Callies
Professor of Law
University of Hawaii at Manoa

IN RE: Ocean Thermal Energy Conversion (OTEC) Onshore Impacts, Their Mitigation and Regulation

I. INTRODUCTION

This memorandum fulfills a commitment to the State of Hawaii Department of Planning and Economic Development via Parsons Hawaii to produce a draft report on certain issues regarding the impact of the construction and operation of OTEC facilities in Hawaii's coastal waters. The contract with Parsons (Purchase Order No. 6174-3-PR001) is based upon a proposal made to Mr. Kent Keith, Deputy Director of the Department of Planning and Economic Development setting out the potential relevance of oil/gas platform development and deployment in Scotland and, to a lesser extent, in Houston and New Orleans to Hawaii's potential OTEC program. This memorandum is therefore organized around the issues raised in the noted proposal and deals primarily with the land use impacts of the various phases of oil/gas exploration, platform construction and development of resources. It is based on the assumption that Hawaii will go to an offshore as opposed to a shore-based facility or facilities for the development of OTEC as an alternate energy resource. Therefore, it deals primarily with the visual impact of platforms during construction and the plans and regulations promulgated in an attempt to reduce impacts as much as possible. No attempt has made to assess the visual impact of such platforms in place (at a drill site) as the closest was a nearly invisible 17 miles offshore. Technical environmental data are beyond the scope of this investigation.

As detailed in the attachments and references, this memorandum is based upon interviews conducted and materials gathered in June and July of 1981, principally in Scotland and elsewhere in the United Kingdom of Great Britain and through extensive correspondence and preliminary literature survey conducted in March, April and May 1981, in contemplation of and preparation for the trip. Citations and references follow the format of informal academic papers: last name of author or interview source. Full references are listed in the Bibliographic Reference at the end of the memorandum.

A. Assumptions and Scope

1. OTEC and the Likelihood of Adverse Visual Impact.

The OTEC process relies primarily on the temperature differences between warm surface water and cold deeper water to produce electric energy by using the warm water to vaporize a fluid which then drives a gas turbine. The vapor is then condensed by the cold deep water and recycled back to be vaporized again by the warm water. This so-called closed cycle form of operation (open cycle uses sea water), the one utilized in Hawaii, may apparently be either shore-based or offshore based, but the primary - indeed the only, to the author's knowledge - method of using this technology appears to be offshore based, either bottom-resting, floating, or moored to the bottom. Presumably the bottom-resting type, which is most similar to present oil/gas platform types, will perforce be located in water which is shallower than a moored facility. The latter may not, however, be able to sustain the same amount of equipment or men. Both types require a reasonably long vertical shaft, but it is the author's understanding that this shaft will most likely be shorter than either the supports for the bottom-resting type or the moored type of OTEC plant. In any event, Hawaii's principal experiments have been conducted from a barge or boat which most closely resembles the moored type, though it is possible that significant development of this resource will rely on the bottom-resting type, which looks very like an oil exploration or production platform (Harms/Gutshall).

In either event, while pollution concerns associated with oil and gas exploration and production are not likely to be issues, it is clear that considerable visual impact may be foreseen in both the construction and "production" phases of OTEC power generation, though it is possible that a moored facility might require less visual disruption than a platform resting on the bottom of the seabed. As described in some detail below, the primary concern of such impact would be on the quality of view disruption for residents and tourists from Hawaii's famous beaches and other coastal areas and, to a lesser extent, from its mountains. If it seems appropriate to construct an OTEC platform of either type in Hawaii (because of the number of platforms needed either for Hawaii or as part of a new OTEC facility-producing industry or because of the costs to produce one elsewhere and tow it to Hawaii) then, as described in more detail below, it will be necessary to identify a protected bay-like environment for such a construction site. Although there are substantial employment and commercial advantages, potentially, for so doing, even an exploration rig for the oil industry is usually several hundred feet in height, owing to the need for a structure that both reaches (or in the case of a moored facility, reaches part way) the ocean floor and extends above the surface far enough so that the largest of the recorded waves in the area of expected operation will pass beneath the working platform itself (once estimated to be in excess of 60 feet in Hawaii). Therefore, also as set out in more detail below, depending upon whether the platform is likely to be made of concrete - which is constructed in an upright fashion - or steel - which is constructed on its side and then tipped upright at the operation site - an OTEC platform construction site, during at least part of any construction period (which may range from a few months to several years depending upon the size of the platform) will be several stories high - and therefore highly visible for long periods of time.

Once in place, such platforms will almost certainly be visible from great distances, though the visual intrusion may be greatest from nearby beaches, headlands, cliffs and mountains (see photographs of steel platform at Nigg Bay). Owing to the relatively steep falling away of the ocean bed and the tremendous depths of the ocean just a short way from most of Hawaii's coast, it is likely that such platforms, once in place, will be relatively close to the shore, where the energy produced can be quickly, easily, and less expensively transmitted to shore for use. It is, of course, conceivable that an entirely shore-based OTEC facility can be constructed that, while having about the same visual impact as a conventional power plant (Harms/Gutshall), would nonetheless be less visually prominent and from many fewer places. However, the author is not aware of any experience with such shore-based OTEC facilities. While such platform construction became a tourist attraction in Scotland, where most tourists come for inland rather than coastal amenities, it is difficult to conceive of anyone coming to Hawaii, where most tourism is directed toward beach and beach views, to see an offshore platform.

There are, finally, a series of secondary coastal impacts that will flow from offshore OTEC technology, the degree of which will largely depend upon the level of construction and number of OTEC production sites ultimately developed. As noted in more detail in the discussion of the Scottish experience, the construction phase, which may be quite long depending upon whether platforms are constructed for Hawaii only or for a Pacific Basin market, should one develop, is reasonably labor-intensive. Often, subsidiary fabrication and storage facilities spring up nearby. The labor force must be housed, families fed, and children educated. This may entail a shift in population centers during this phase. Moreover, during the production phase, the platforms must be manned and maintained. This means boats, crews and terminals, that may not presently be available in the right place or in sufficient quantity.

2. The Oil/Gas Industry Analogy and Lack of OTEC Experience.

Except for the pilot projects that have proved so highly successful in demonstrating electrical energy production, there does not appear to be any significant OTEC development elsewhere to which one can turn for guidance on visual coastal land-use impacts of the OTEC energy production process, in either the construction or the production phase. This is largely confirmed by conferences with various governmental and academic departments dealing with alternative energy as well as oil/gas exploration in Scotland and elsewhere in the United Kingdom. However, that part of the oil/gas development industry that relies primarily on ocean exploration and production facilities is analagous, as reading (Lewis and

McNicoll) and interviews (Mackenzie, Pickett, MacLeary, Henderson, Cameron) confirm. Both require a construction (whether of exploration or production platforms) phase, to produce the main structure to be utilized. Then, both contemplate a production phase, to tap the energy resource, in or over ocean water of reasonable depth. In both, construction is usually reasonably near the eventual site of production. In both, some servicing, monitoring and maintenance will be necessary so long as the platform is in place. It is interesting to note in passing that whereas an OTEC platform's "life" is probably measured in terms of its ability to "last," an exploration or production platform's life is sharply curtailed by the quantity of oil and gas produced from the site. Surprisingly, there are apparently no plans for the multiple use of these platforms. They are designed to be blown up and sunk at the end of their useful life, despite the fact that they cost tens of millions of dollars each to fabricate and set in place, and that, at least in theory, the steel variety could be cut loose and towed elsewhere (though corrosion may be a factor in such decisions).

3. Oil/Gas Technology in Brief.

As noted above, the principle points of analogy between OTEC and oil/gas technology is in the construction, placement, use for production and monitor-service-maintenance of an ocean platform. There is nothing analagous to the exploration phase of the oil/gas industry for OTEC in terms of time and equipment, except to the extent that a small rig of the type normally used for exploration rather than a production platform might be sufficient for a level of OTEC energy production.

For the rig, capable of operating, say, in depths of up to 300 feet (more if it is of the semi-submersible variety) a crew of 50 to 60 men with a variety of equipment to permit it to be moved about and drill is typical. Modifying it for OTEC, one could presumably still expect the following equipment aside from the structure itself to be needed: (Lewis and McNicoll)

Accommodation modules
Derricks/cranes for bringing on supplies and equipment
Heliport and/or docking facility
Radio/radar equipment
Miscellaneous pipes and valves
Miscellaneous electrical and pumping equipment

Personnel that would be needed from the usual list: (Lewis and McNicoll)

Engineer
Control room operator
Derrick/crane men
Electrician
Plumber
Radio operator
Maintenance man
Roustabouts
Galley man
Welder

The more a moored-type of structure were used, which would be similar to new oil/gas platform technology of the tethered bouyant platform (TBP) variety, the more it would resemble the above description of the exploration rig, without the motors and ability to move about. The larger rigs, capable of operating at greater depths, would involve, presumably, only a marginal increment in crew for maintenance, but would be longer in the construction phase. These operate presently in the North Sea at depths up to 700 to 800 feet. Examples follow in Part II in the discussion of Scotland. (Lewis and McNicoll; Henderson; MacKenzie).

The construction phase is the most labor-intensive and consists of the design, construction and delivery and erection of the platform itself. While its outfitting (see list above) may spin off sufficient subsidiary commercial ventures to have an onshore impact, most of the equipment is readily available elsewhere in the world and is of sufficient high technology that it may be difficult to commercially justify similar operations in Hawaii. The construction phase would entail the laying out and building of a yard adjacent to a well-protected bay sufficient to construct platforms. If concrete, which rest on the seabed when in place usually by virtue of their own weight, then considerable depth to test (200 up to 600 feet) and set them up for towing is needed. As they are constructed vertically, the concrete platforms are, unless screened by mountains, usually visible from great distances as they will be 20 stories or more in height in the last phases of construction (though far less visible when in place). If steel, less depth of bay is required (about 50 feet) as these are both constructed and towed to the site horizontally, though much longer horizontal area is accordingly needed to assemble the larger ones, (as will appear from the discussion below on the behemoth being constructed at Nigg Bay in the Scottish Highlands), as compared to the concrete ones once assembled at Loch Kishorn in a popular coastal area on Scotland's scenic west coast (Nigg Bay is on the less scenic, east coast). As noted before, the latter became a tourist attraction of some repute, and was in addition fairly well-shielded visually by steep mountains from much visual disruption. It is also worth pointing out that some backup facilities and services will be needed in the form of roads, water and sewer hookups, electricity and the like.

4. The Choice of Sites.

The choice of sites was largely dictated by the author's reading and writing contacts as well as some earlier travel plans to which this project was joined. Scotland in particular has a wealth of experience with the fabrication and placing of dozens of rigs, from the mammoth (700-plus feet) production platforms at Nigg (steel) Lock Kishorn (concrete) and Cruden Bay, to the smaller production and exploration rigs at Cruden Bay and Ardesier. There is also much experience with onshore terminal facilities in the Shetland and Orkney Islands. All have experienced considerable secondary impacts - development of housing, related commercial enterprises, some infrustructure strain. While much of the work force eventually came from outside the immediate community for the construction phases (most of which have now been ongoing for ten years or so), the workers are for the most part Scottish or, at worst, northern English or Irish, so that the jobs created did benefit the regional population which had construction-related skills. Much of the special equipment, on the other hand, came not only from outside Scotland but outside Great Britain altogether. Nevertheless, as appears below, the local populations nearest the construction sites were by and large favorably disposed to their location, primarily because of the expected and realized employment and other economic benefits, even in the areas partially dependent upon tourism. Indeed, one expert remarked in the course of our conversation that OTEC platform construction seemed to him to be a potentially "nice industry for Hawaii" (Mackenzie). As noted above, however, Scotland has no experience with permanently affixed platforms offshore as the nearest is barely visible at 12 miles offshore Helmsdale. However, what was done to explore, discuss and mitigate the substantial impact of such structures in the fabrication stage, (where they are often far more visible being often totally out of the water which otherwise covers at least 80 percent of their bulk), is well worth the analysis that follows in Part II. The following is a summary of salient points that surfaced during a brief literature and onsite investigation, rather than an in-depth study and analysis, which may well be worth doing if Hawaii is going to proceed with OTEC, but which would take several weeks longer to complete, in Scotland alone, as noted in the conclusory section.

II. SCOTLAND: VISUAL IMPACT OF PLATFORM CONSTRUCTION IN PART OF ANOTHER ISLAND STATE IN COASTAL AREAS

A. Relevant Oil and Gas Industrial Development in Scotland: An Overview

The finding of vast oil and gas reserves in the North Sea and the proximity and availability of sites from which to seek out, develop and service production wells in Scotland resulted in the transformation of much of Scotland's coastal population centers, as well as some previously isolated and sparsely populated areas. By the close of the first decade of development, upwards of 60,000 jobs were created in 14 communities, of which nearly 50,000 still remain (Lyddon; North Sea Information Sheet). While most of this development occurred in and around the less scenic and more proximate (to the production areas in the North Sea) east coast cities (Dundee, Aberdeen, Inverness) nevertheless substantial development also occurred in the Clyde Firth, and at Loch Kishorn for construction of platforms (see discussion below) as well as the remote Orkney and Shetland Islands to the north (see below). Indeed, by February of 1981, over 6,000 people were employed in building platforms alone, with an additional 19,000 employed in services such as catering, marine transport, warehousing, and inspection. Less than a quarter of the total employed were engaged in the so-called primary industry of exploration and production - the two categories less relevant, incidentally, to Hawaii (Fact Sheet).

The major land-impacting development that is most like the type that could similarly affect Hawaii appear to be as follows:

1. Inverness (including east coast Nigg Bay and surrounding firths): Steel platform construction, backup services and steel fabrication.

2. Peterhead (east coast): Service and repair base for exploration rigs.

3. Aberdeen (east coast): Regional headquarters for a number of oil firms; offshore service base; huge influx of related industry fabrication or warehousing (pipes, etc.).

4. St. Fergus (east coast): Petrochemical with some service of offshore exploration.

5. Cruden Bay (east coast): Shore transfer terminal - vaguely similar to what might come ashore from OTEC platform to deliver electricity - entirely hidden under dunes and golf course with the exception of two pump tanks.

6. Dundee (east coast): Offshore service base and module fabrication center.

7. Flotta (Orkney Islands): Receiving terminals and plants.

8. Sullom Voe (Shetlands): Terminals.

9. Loch Kishorn (west coast scenic area): Concrete platform construction.

10. Clyde Estuary (west coast): Concrete platform construction.

Each of these is discussed either individually or in the context of particular issues below.

B. The Planning Control Context: An Overview

Land use planning in all of the United Kingdom of Great Britain, including Scotland, is governed by the national Town and Country Planning Acts, the latest principle version of which was promulgated in 1980, though for purposes of this discussion, little of consequence happened since 1968 (Callies, Callies and Garner, Young, Moore, Heap, Cullingworth). Basically, no development is permitted without specific planning permission from the local government in whose jurisdiction the proposed development is to take place. Up until 1981, this was nearly without exception and general classes of permissions which were automatically deemed to be granted for certain classes of development were virtually unheard of. (Recently, these last have been expanded and, in certain economically and physically deteriorated areas, called enterprise zones, land use controls will be virtually lifted altogether.) Thus, while certain broadly worded structural plans (similar to Hawaii's State Plan, Act 100) and narrowly drawn and mapped development plans (similar to Hawaii's County Development Plans) are in theory to guide the local governments in granting (or not) planning permission, there is no legal requirement that the local government be bound by the contents of either document, although there is a risk of being overridden by the central government's Secretary of State for the Environment on individual decisions. At certain stages of the planning permission hearing and application process, various parties have rights to demand a public inquiry, a sort of full-blown, long and expensive public hearing to thresh out most of the issues (Young, Fisher). This usually occurs when certain major objections are officially made and unresolved.

In any event, as the land-based developments associated with oil/gas exploration were rightly expected to be large and with major impacts of a land use nature, the Secretary of State as Planning Minister for Scotland directed that all major oil-related developments should be ultimately referred to him so that he could make the final decision "if necessary" (Lyddon), although the initial application did in fact go to the appropriate local government authority first. Between 1970 and 1979, 78 such major applications were made, and although some (including seven oil refineries and a dozen platform construction yards) were never built and in some cases never approved, five major oil and gas terminals, 11 platform yards, five major pipelines and 54 other developments were so approved without either major objections or public inquiry (Lyddon). Of the four public inquiries that were held, all involved platform construction yard applications in sensitive, scenic west coast regions (Lyddon).

A prime tool in keeping down the level of objection and provision of national guidance to local governments as to what would be nationally acceptable development where, was the series of National Planning Guidelines issued to set area development priorities. The Guidelines form the basis for the Secretary of State's assessment of developments which are thought to raise national issues, and are to be taken into account by local governments in both the preparation of plans and the execution of development policies. General guidance is set out for large-scale industry, agriculture, forestry, nature conservation, landscape and recreation, and the coast. Further more detailed guidelines were issued for specific subject areas, and in 1974, such a set was issued entitled North Sea Oil and Gas Coastal Planning Guidelines. Noting that the pressure of such developments clearly demonstrated the need for national policy guidelines on the way in which such developments should take place, the central government provided that certain areas should be designated as "preferred development zones" where such development should be appropriate and should be encouraged, and "preferred conservation zones" areas of particular national scenic, environmental or ecological importance in which such development would, in general, be inappropriate and justifiable "only in exceptional circumstances." For the latter, the central government relied on an official coastal survey which set out the resources of the Scottish coast. The government noted that the zones did not always conform with local land use plans and directed that they should not be regarded as rigid. In setting out the criteria used to make the zone designations, the Guidelines noted that to some extent the government was forced to compromise between a scenic area and the particular needs of industry for platform construction (deep and weather-protected bays).

The Guidelines then specifically designated 16 preferred development zones, including Aberdeen, Peterhead, the Orkneys, the Shetlands, the Clyde area, Dundee - indeed most of the areas actually developed. It then set out 22 preferred conservation zones, including some very near to, or identical with, some areas that were in part developed, such as the Black Isle across from the major development at Nigg Bay near Inverness, and St. Fergus, whose fine sand beach and high dunes were in fact preserved as noted above and below. Noting that any intrusion into the zones would have to be justified by compelling arguments, including a demonstration that no suitable sites existed "outwith a preferred conservation zone," the Guidelines designated virtually the whole of the west coast for a distance of 1,100 miles a conservation zone. Hence the need for an inquiry concerning the concrete platform yard eventually permitted at Loch Kishorn near the Isle of Skye. To some extent the designations were aided by the designation of much of the north Highland area as Areas of Great Scenic Beauty, the closest one can come to a national park (there are none) in Scotland. In general, the following guidelines were used in designations:

1. A coastline with scientific, ecological or scenic features which would be vulnerable to development.

2. Particular sections of the coastline where an existing or proposed use would be incompatible with major oil and gas developments.

3. Areas of the coast containing small scale communities whose expansion might cause serious economic and social problems.

4. Areas of the coast with towns and villages whose character should be protected.

5. Tourist and recreation areas or other places where developments other than major industrial processes should have priority.

While the Planning Guidelines provided considerable guidance for shore-related oil/gas development, it is worth noting that national conservation-preservation designations are common to Scotland under other legal authority, as is the case in all of Great Britain. Thus, while the central government failed to authorize the designation of any national parks in Scotland, it did authorize first the designation of Areas of Great Landscape Value (AGL's), Sites of Special Scientific Interest (SSI's) and, in the late 1970's, National Scenic AReas (NSA's). Development in any of these areas cannot simply be permitted by the usually all-powerful local authority. The statutorily created Countryside Commission, the guardian of the national countryside, must, by recent regulation and statute, review all development for which local planning permission is granted in such area, and in the event of a dispute between the Countryside Commission and the local authority over the manner or placement of such development, the matter goes to the Secretary of State for the Environment for resolution. By 1981, the NSA designations alone covered 20 percent of the Scottish Highlands. There is evidence that while such large percentages may be popular in England and elsewhere in Scotland, it is resented in areas of low employment and economic activity where the local population would prefer a more even balancing of conservation against economic activity. They do not see themselves as a "green lung" for the rest of the United Kingdom (Cameron).

There was also much use of reports and impact analyses, some 54 being completed in the first nine years (Lyddon).

C. The System in Practice: The Handling of Specific Projects

Much of the development relating to such oil/gas construction activity as might relate to Hawaii has taken place - as the Guidelines suggested - in Scotland's comparatively less attractive and less tourist-oriented east coast. With the exception of St. Fergus noted above and below, comparatively little effort was made to mitigate the visual effects of this development.

1. The Orkney Islands and Flotta.

An exception of sorts is Flotta in the Orkneys. As noted previously, the development there consists not of platform construction, but of facilities needed to bring ashore and process petroleum products. While there would certainly be differences from the onshore facilities needed for transferring energy from an offshore OTEC platform, nonetheless there are some striking parallels as well. The Orkneys are offshore islands, for the most part sparsely populated, flat and barren, making any sizable structure visible for some distance. Moreover, climate and soil is such that the planting of large trees to screen such developments would be impossible. The structures themselves, both storage tanks and others, could be expected to be several stories high and several hundred feet long. Before planning permission was eventually granted, therefore, several interesting techniques were employed in order to mitigate, if not eliminate, the visual intrusion:

a. By means of models and computer checks, various visual profiles were devised for potential sites of the structure, and the ones chosen were those which apparently best reduced the apparent size of the structures through use of berms, fill, lower land areas, and the grouping of the structures so as to blur their hard edges and separate definition from as many viewpoints as possible.

b. Chips of various paint colors were laid on color photographs of the site, and the least prominent were then placed on large panels at the site, so that colors which most blended with the typical heather moors could be chosen to reduce the prominence of the structures.

c. What bushes and grasses that would grow in the areas were planted on the site, especially on the berms and other areas where the soil was disturbed and exposed.

The social impact of new technology and the influx - even temporarily - of thousands of workers into an area of traditional crafts and husbandry with a population of around 1,700 was substantially mitigated by choosing the relatively uninhabited island of Flotta, with a total population of 73, for the major development. While there was therefore major disruption there, it was sufficiently isolated from the other islands so as to comparatively minimize impact to the rest of the Orkneys. Indeed, it has been observed that, as the population on Flotta had declined from 425 to 73 in the past 100 years, the development of the terminal facilities may well have prevented Flotta from becoming wholly uninhabited in a few years (Robertson). The main facilities - berths both adjacent to the shoreline at Scapa Flow and offshore single mooring bouys for supertankers-presently employ approximately 90 people, two-thirds of which are local (Wave Generation Report).

2. Loch Kishorn and the Construction of Concrete Platforms in a Designated Conservation Area.

The concrete platform construction yard at Loch Kishorn is one of two proposed on the scenic west coast of Scotland in an area of striking natural beauty (inland-directed) and consequently high tourist attraction and value. The second, near Drambuie, never received permission after a full-blown planning inquiry, largely because the National Trust decided such use of its land at the site would be contrary to the terms of its duties as landowners (Pickett). However, the Howard-Doris platform construction site at Loch Kishorn was approved. An Environmental Impact Assessment made in early 1977 identified several adverse impacts, most of them visual:

-quarrying of gravel nearby for construction
-construction of a dock
-wet site for platform tower formation
-noise
-lights at night (night work)

The platform towers themselves have the biggest visual impact. The last one was 650 feet high when finished, although such platforms are at that height for only a small part of the construction period, and at lesser but nonetheless intrusive heights for considerable additional periods. Of a more permanent nature: several cranes at 120 feet and a main building at 85 feet.

But as the Impact Assessment makes abundantly clear, the visual impact, while substantial, is very localized due to steeply sloping hills into the Loch itself. It is the local community that is principally affected, and interviews conducted with the local population indicated almost no unfavorable reaction. This is perhaps attributable to the already noted local view that amenities ought to be balanced with the need for economic development and jobs. Indeed there is some evidence that the platform construction yard, and especially the huge platforms themselves, became something of a tourist attraction. While the construction yard employed 1,700 at its peak, most were from outside the immediate area, though for the most part within Scotland itself (Pickett; Wave Energy Generation Report).

3. The Shetland Islands and Sullom Voe.

Sullom Voe in the Shetland Islands represents another oil terminal development. Temporary construction workers number about 2,000, mostly from outside the Shetlands, requiring, incidentally, about 550 extra housing units (those for Flotta were temporarily housed in workers' camps). Population accordingly rose from 700 to over 3,000 during construction. (Wave Energy Generation Report). As in the Orkneys, the visual impact, is limited due to the isolation of the islands (Bisset). The impact on traditional lifestyles and products such as Shetland woolens is affected, though by how much is not clear. While women are said to neglect their knitting in favor of higher-paying cleaning jobs, and infrastructure is said to be strained (Paget and Lloyd), it is not clear that this is anything more than a temporary shift the money from which will enable locals to undertake private capital improvements to property and make other "one-shot" purchases during these relatively good times (Pickett, Mackenzie).

4. Clyde Estuary: Anatomy of Multi-Site Impact Analysis.

In the mid-1970s it became clear that a prime site for the construction of platforms would be the Clyde Estuary near Glasgow. The Scottish Development Department and the Department of Energy commissioned an impact analysis of the construction of such platforms at 16 possible sites (Holmes). Indeed, it was suggested that by heavily utilizing the Clyde, with its relative proximity to Glasgow, other more scenic areas could be spared altogether. While this was rejected by the authors of the Report on the ground that what scenic areas there were in the Clyde Estuary were more important that those elsewhere on the west coast (because the Clyde was near to so many more people and, therefore, the impact could be said to be greater), nevertheless the sheer number of the sites considered clearly indicate the level of expected development.

As with the other sites, social and economic impacts were discussed, including the likely spin-off for the cement industry if platforms made of concrete were constructed in the area. However, for our purposes, the major points of interest have to do with the concentration on visual impact.

It was first noted that the Clyde Estuary was characterized by varying degrees of steep coastal inlets. Sufficient water depth permitting, the preferable sites from a visual perspective would be those which were both as remote as possible from population centers and as hemmed in as possible by higher land forms, thus restricting the view of the platforms from as many points and to as few people as possible. There was great skepticism expressed concerning the likelihood of platforms between 450 and 800 feet in height continuing to be tourist attractions, and about the return of tourism, once negatively affected for a period of years, after the period of platform construction came to an end.

The Report considered the visual impact of a platform in its construction stage on the estuary and effect on the character of the landscape. Only three other major factors dealing with land (transportation, retention of agriculture, and reinstatement of the site) were discussed in detail. The Report then analyzed each of the 16 sites, often sketching the platform as it would appear in its most intrusive phase against the particular landscape. All critical land use factors, including nearby historic, scientific, scenic and other critical environmental factors, were placed on a location map of the area. A "site visual containment boundary" was drawn around each site, together with contours and screening potential. Then the various major criteria were subdivided and ranked, and matrices devised showing, first, the ranking of each site in each category, and then the ranking of the sites by the sum of all categories. While highly subjective, the exercise represents a reasonable manner in which to rank sites for such visually intrusive developments provided there is a choice as to location. It is not clear there is such a choice of locations for potential OTEC platforms in Hawaii.

5. Cruden Bay: What Impact?

Located on one of the few areas regarded as scenic enough to warrant protection on Scotland's east coast, St. Fergus represents an example of how to design an onshore terminal to make it as visually unobtrusive as possible. The major pipelines from the production areas onto the shore pass beneath both fragile dune areas and a golf course, with nary an indication that they are there, except for the presence of two pump station tank-like structures.

6. Inverness-Nigg: What Bay?

The contrast with the platform (steel) construction yard and storage facilities at Nigg Bay could not be more pronounced. The construction there of one of the world's largest steel platforms, though lying on its side, dominates the bay which is otherwise scenic, from virtually any vantage point (see photographs attached). It is not, however, visible from Inverness itself, but only from scattered communities up and down the bay, so that while the visual intrusion for those who can see it for miles around is great, those numbers are small. That intrusion, however, is very, very great.

7. Peterhead: Impact, yes, but then, whats to save?

The exploration rigs are not nearly so large as the platform at Nigg, though they are dozens of feet high in a community with little else over four stories. The contrast between the north side of the harbor where small boat fishing predominates, and the south side where the rigs are, is pronounced, and visible from any point on the bay itself (see attached photographs), and for a few miles around, though often not from the town itself which spills gently down a hill in many parts to the sea, often down narrow streets with few views anyway. Moreover, it would be difficult to find much redeeming charm in Peterhead on even a good day, which is not common in this part of Scotland. It therefore can be argued that the choice for such facilities here, though both visually intrusive and smack against a population center, is a good one. This should be contrasted with St. Fergus, which has little there except oil facilities, no particular scenery different from other parts of the east coast, and little in the way of nearby roads from which the development is particularly extraordinarily visible.

8. Dundee and Aberdeen.

Both of these are regional centers of population which have grown substantially due to the impact of the North Sea oil/gas industries for which they serve as headquarters and manufacturing centers, though the former is in decline. As a result, while a great deal is visible from the water front, little is visible from elsewhere. Of course, neither is as sea-oriented as it once was, and tourism focuses not so much on their immediate beach areas (though nearby beaches they have, which are used a good deal locally and regionally for holidays) but on various historic aspects of the towns themselves - their old areas - or on long estuaries from which the oil/gas facilities are but dimly visible, if at all. Thus, crossing the British Rail bridge across the river estuary into Dundee, one is aware of substantial harbor and dock facilities in the distance, but not of any particularly intrusive structure. Of course, neither is presently constructing large platforms in the city environs. (Ardesier is a few miles distant).

III. TEXAS AND LOUISIANA: A CURSORY OVERVIEW

Texas and Louisiana represent states in which major oil companies have engaged in considerable offshore exploration, drilling and production for decades (Riley). Discussions with oil company executives, together with comments from a few independent experts, indicates they have done so largely free of regulation. Not surprisingly, oil exploration and production platforms and the odd onshore facility are by and large regarded positively, as signs of growth and progress. Significantly, much of the equipment is located either in areas not generally regarded as tourist-oriented or scenically valuable by the residents most impacted, or they are sufficiently far offshore to be visually irrelevant. No one reported being subject to a regulatory regime which hindered location or size of either construction or placement of oil exploration and production equipment. However, information gathered is sketchy and often second hand in these locations, as visits were confined to one-day "stop overs."

A. Louisiana

There is considerable activity in Louisiana both in the fabrication of oil exploration and extractive equipment and its location in coastal regions. Those interviewed appeared to have considerable experience in dealing with platforms and other exploration/production equipment. It was suggested that OTEC in Hawaii could use the semi-submersible type of platform widely used in lengths exceeding, say, 1,500 feet, tethered to the bottom by up to eight anchor cables. It was pointed out, however, that such platforms, while stable and large, were expensive and that perhaps Hawaii could make do with a vessel similar to a drillship instead. This could have several advantages:

1. Cost. Much less than the least expensive platform.

2. Reliability. Could move to optimal temperature conditions for OTEC process, disclosed via computer-linked sensors. As there is no need to remain fixed to a precise given area on the ocean floor, the stability afforded by a platform might not be necessary. It was pointed out that it takes at least three days to move a tethered semi-submersible platform.

3. Less Visual Interference. A more acceptable sight on the Hawaiian seascape.

There may, however, be disadvantages:

1. Interruption of Service. While such vessels are very seaworthy, they must often be disconnected in the event of a storm, both to manuever and to get out of its path. Semi-submersibles are relatively impervious to ocean storms, constructed as they are to an operational platform height above the highest wave generated by a 100-year storm.

2. Size. It is not altogether clear that an offshore ship could hold sufficient equipment for an OTEC facility which could produce a significant percentage of energy.

Trade publications, together with slides provided by contacts at AMOCO, demonstrate the visual effects of both ship and semi-submersible platform.

B. Texas

As in Louisiana, Texas appears generally to welcome platform construction and placement (indeed all energy industrial activity) wherever placed. Except for the long gulf coast barrier island that is Padre Island, there is little coastal tourism in Texas, especially for non-Texans. The Texas altitude toward the gulf coast coastal zone is perhaps best exemplified by a recent reconsideration of participation in the Federal Coastal Zone Management Program, in which Hawaii is a recognized leader. Padre Island is probably in a reasonable state of preservation due to its federal designation as a National Seashore.

Nevertheless, the oil industry appears to have done a reasonably thorough job in preparing environmental impact assessments for certain of its projects (OCS EIS; Mid-Atlantic Regional Study).

These tend to discuss principally nonvisual attributes of the projects being proposed, however, and so are of little value as models for assessing such impacts in Hawaii. On the other hand, the EISs go extensively into probable socio-economic effects. These, together with studies such as the Rice Center Sabine Pass Economic Base Analysis and the Conoco "Reference for Operating Managers" provide an excellent format for assessing the likely impact of an OTEC platform producing facility in Hawaii. The former is particularly strong on assessing employment potential.

Conversation with an industry representative indicates that an indigenous OTEC platform construction industry would be relatively unobtrusive only if the platforms were very modest in size.

ARCO's district engineer was good enough to provide pictures of typical facilities, two of the most pertinent of which are attached.

IV. ALTERNATIVES TO OTEC: WAVE ENERGY AND PUMPED STORAGE

Hawaii is a leader in a variety of alternative energy sources. Indeed, most sources interviewed expressed interest not only in learning more about the State's OTEC experiments, but also its wind energy and geothermal production. However, two additional techniques have received considerable attention in Scotland and Wales, respectively: Wave Energy and Pumped Storage.

A. Wave Energy

In Scotland in particular, the use of energy generated by various devices floating upon or just beneath waves is a matter of considerable interest and investigation at a number of institutions (Implications of Wave Energy Generation). Among the more popular:

1. Salters (Nodding) Ducks.

A string of vanes on a central core, each string 1,040 m long parallel to the waves. Energy derived from oscillation of the waves.

Each "duck" to be 24 m long, 20 m high with a 20-m draft, weighing 250,000 tons (concrete) each.

2. Cockerells Contouring Rafts.

Series of hinged rafts in lines at right angles to waves. Energy derived from movement between hinges. 2,500 units, each 50 m long, 7 m high, with a 3-m draft, 15,000 tons (concrete) each.

3. NELs Air Pressure Buoy (Oscillating Water Column).

A vessel with open end under water. Rise and fall of internal water level forces a reservoir of air through a turbine. 100 each 143 m long, 52 m high, 25.5-m draft, 95,000 tons (concrete) each.

4. Russell Rectifier.

On seabed, two compartments. Valves from one to the other create a head which will drive a turbine as water runs from higher to lower. 1,400, each 140 m long, 63 m high, at 175,000 tons (concrete) each.

The best wave activity is estimated to be an area about 8 miles west of the Hebrides and over a hundred miles long. It is estimated it would take about two to three weeks to moor the units, and 20 monitoring substations at about 15 men per station, per team (two each to rotate). There will, in addition, need to be supply boats, ocean-going tugs and crews for them. The port and construction facilities are estimated to be similar to those needed to construct oil platforms. There would, of course, be power transmission problems (onshore) similar to those for OTEC. It is worth noting that one of the key objections to wave energy in Scotland is the need to put the transmission lines across the Isle of Skye, one of the premier scenic areas in western Scotland and a major tourist destination. Cable costs underground are thought to be prohibitive.

B. Pumped Storage in Wales

A further alternate energy source, used so far only as an emergency "reserve" in Wales, uses two pumped storage power stations located off Ffestiniog and Dinorwic. The former has been in operation for some time; the latter is still under construction.

Basically, pumped storage power generation is identical to conventional hydroelectric power generation, except that the flow of water is artificially maintained by pumping water from one reservoir, a lower one, up to another reservoir, an upper one, by means of electric pumps operating at off-peak or "cheap" electricity user periods. The water in the upper reservoir then flows through spillways and turns turbines to generate hydroelectric power. The systems use about three-fourths of the power generated to refill the upper reservoir from the lower reservoir, so that it is not terribly efficient. On the other hand, the "source" is virtually free once the reservoirs, pumps, pipes, turbines and spillways are in place (Dinorwic; Ffestiniog).

As such a reservoir system in Hawaii would presumably operate within the system of water stored reservoirs already in existence (as, for example, in the Koolaus), the visual intrusion would presumably be minimal. Moreover, there is evidence that the reservoirs become tourist attractions, with the one at Ffestiniog drawing 40,000 visitors a year.

V. CONCLUSION

It is clear from the foregoing survey and analysis that OTEC energy producing facilities will be visually intrusive. The critical question is the extent of that intrusion, and where such intrusion takes place. The experience in Scotland demonstrates that a general land-use management regime, however sophisticated, can be insufficient to deal with a development which, either because of scale or intensity, was simply not contemplated at the time the system was devised. Scotland was part of one of the world's most sophisticated and restrictive systems of land use control, yet it devised a separate regime barely within that system to deal with oil-related development, primarily platform construction, maintenance and repair. The creation of special regulations and guidelines which declare certain areas to be preferable for such development (of low scenic value and/or hidden from view from as many perspectives as possible) and others to be free from such development (due to high scenic value and/or visibility at/from such distances) would appear to be a concept worth further investigation. The Scottish Development Department in Edinburgh would be a good place to start. Contacts there were extremely receptive and two of the managerial staff there are regarded as experts on the subject.

The issue of visual impact mitigation becomes at once more critical and more practicable if it appears possible that Hawaii might develop its own OTEC energy generation facility construction industry. While the numbers of potential visual intrusions increase, the location options also increase. While such facilities cannot be located just anywhere, nevertheless the choice of sites is broader than, say, for the location of an energy producing OTEC facility; after all, the appropriate ocean/temperature conditions are where you find them, and there and only there, can one locate the facility. If all the technically appropriate places turn out to be scenic areas, then a hard choice between alternative energy and preservation may need to be made. However, even here, techniques used in Scotland such as color matching of facilities with environment and the sketching in of the proposed facility on a rendering of a proposed site can help mitigate disruptive visual effects.

Production facilities, on the other hand, can, within limits, be located elsewhere. The academic personnel of the University of Aberdeen's Department of Land Economy are well-versed in such analytical tradeoffs, having participated in a major energy/land use study in the mid to late 1970's. Once again, the general systems of management emphasizing critical areas and development zones have proved relatively successful in managing the visual impacts of such deveopments. Obviously, the impacts covered by secondary development, should Hawaii attract OTEC facilities production ventures, will be considerable and the experience in Scotland would be invaluable. Some miscellaneous observations and conclusions:

1. Coordination among the various agencies which will have to deal with OTEC production facilities is essential. The role of DPED, which has some of the legal responsibility for locating and managing the impacts of these facilities, will be critical, but local government agencies which must cooperate in the permitting process, as well as other State departments, must be brought in at an early stage. Scotland's experience demonstrates the need for this coordination and cooperation.

2. The adaptation and extension of existing management and control systems may be preferable to an entirely new system, in part because the former can react more quickly. However, tailoring a system for OTEC may be possible (and ultimately more useful) if, as it appears, OTEC production is some years off.

3. A wide range of disciplines and skills will need to be brought to bear on the problems raised here and elsewhere. The valuable experience outside Hawaii-Scotland, Louisiana, Texas - can be tapped relatively inexpensively given the costs of OTEC as a whole and the potential for unfortunate consequences should the problems and issues fail to be thoroughly explored. Nothing quite equals personal observation and interviews in places where those problems and issues have already been explored.

4. It has been observed that opposition to energy facilities is greatest where there have been none constructed in the area. If so, Hawaii can expect a lot of community opposition unless job tradeoffs and energy needs are clearly demonstrated.

5. It has also been observed that it is difficult to <u>plan for</u> energy facilities, but easy to "plan to prevent" them.

6. The process of such "planning for" will be critical. To be avoided:

    a. Consider the same issue/issues again and again at each proposed site.

    b. Reopening an issue over and over again in light of constantly surfacing "fresh evidence."

    c. A surfeit of citizen participation whereby everyone demands a say.

Finally, some thought should be given to Hawaii's suitability as an OTEC platform facility manufacturing sites especially if the Pacific Basin market for OTEC developes. Most experts interviewed thought Hawaii has geographically well-positioned for such a facility, and it might make a useful addition for our employment base.

It is recommended that the initial contacts in the important area of management and regulation of OTEC facilities be nurtured and increased as follows:

1. Follow-up letters and information to contacts in Scotland, Louisiana and Texas.

2. In-depth examination and continued monitoring of the management/regulation process.

3. Exchanges of personnel at the Department management level for brief visits to view current situations and discuss issues and alternatives.

We appear to have the time to fully identify the potential problems and investigate alternative solutions. It would be a pity not to use that time wisely.

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February 1981

PIPELINES

	Oil	Gas
Projected		
Under Construction		
Operational		
Compressor Station		

OFFSHORE

	Oil	Gas	Gas Condensate
Discoveries			
Commercially proven field			
Field in production			

Licensed blocks

Designated sea area

7th round blocks in company nominated area

7th round awards in Dept. of Energy designated area

ONSHORE

Oil company operational H.Q.

Offshore service base

Platform construction site-steel

concrete

Module/Other major fabrication site

Pipecoating yard

Oil transhipment and storage

Oil/Gas separation plant

Gas treatment facility

Gas separation plant

Oil refinery

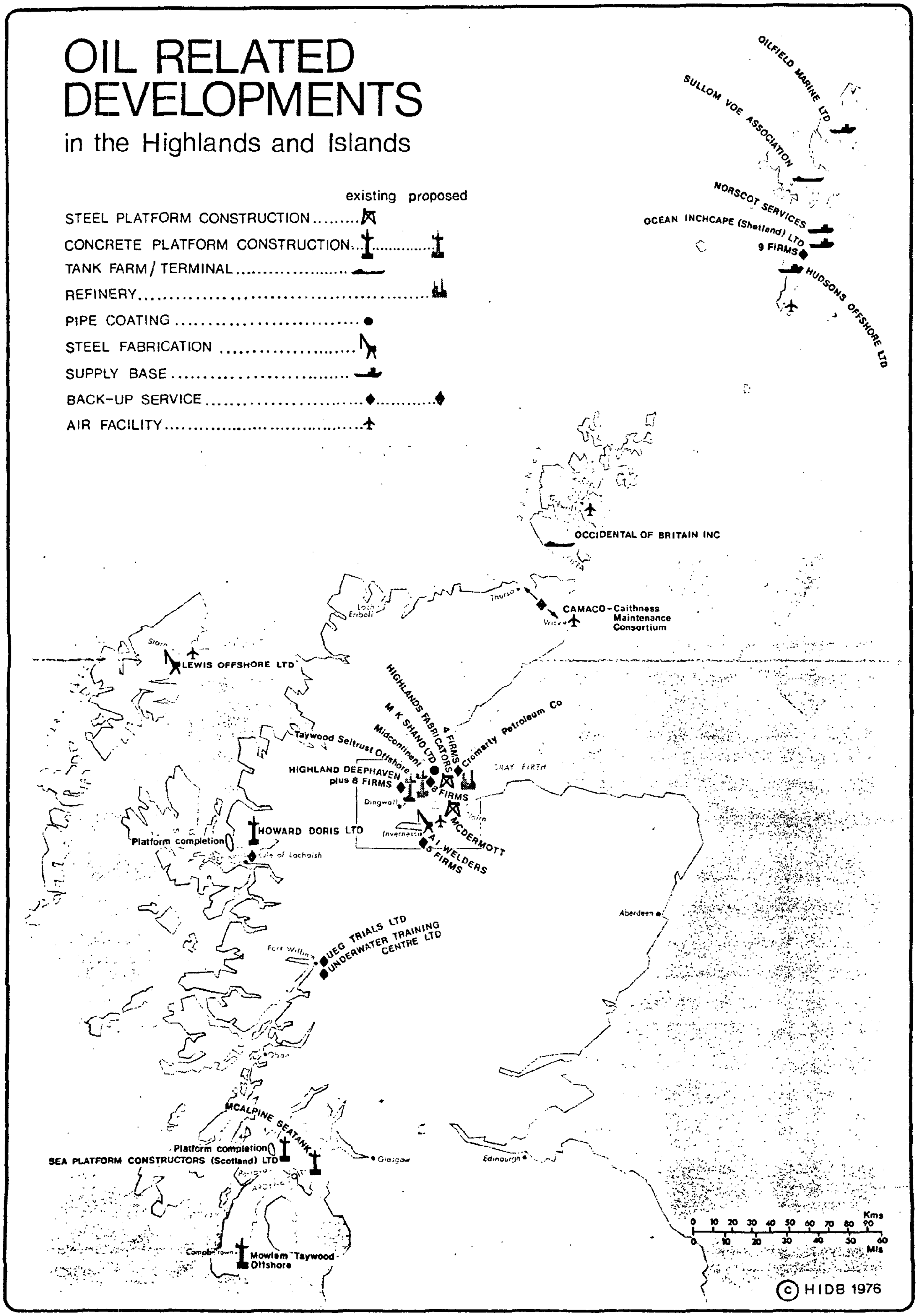
Petrochemicals

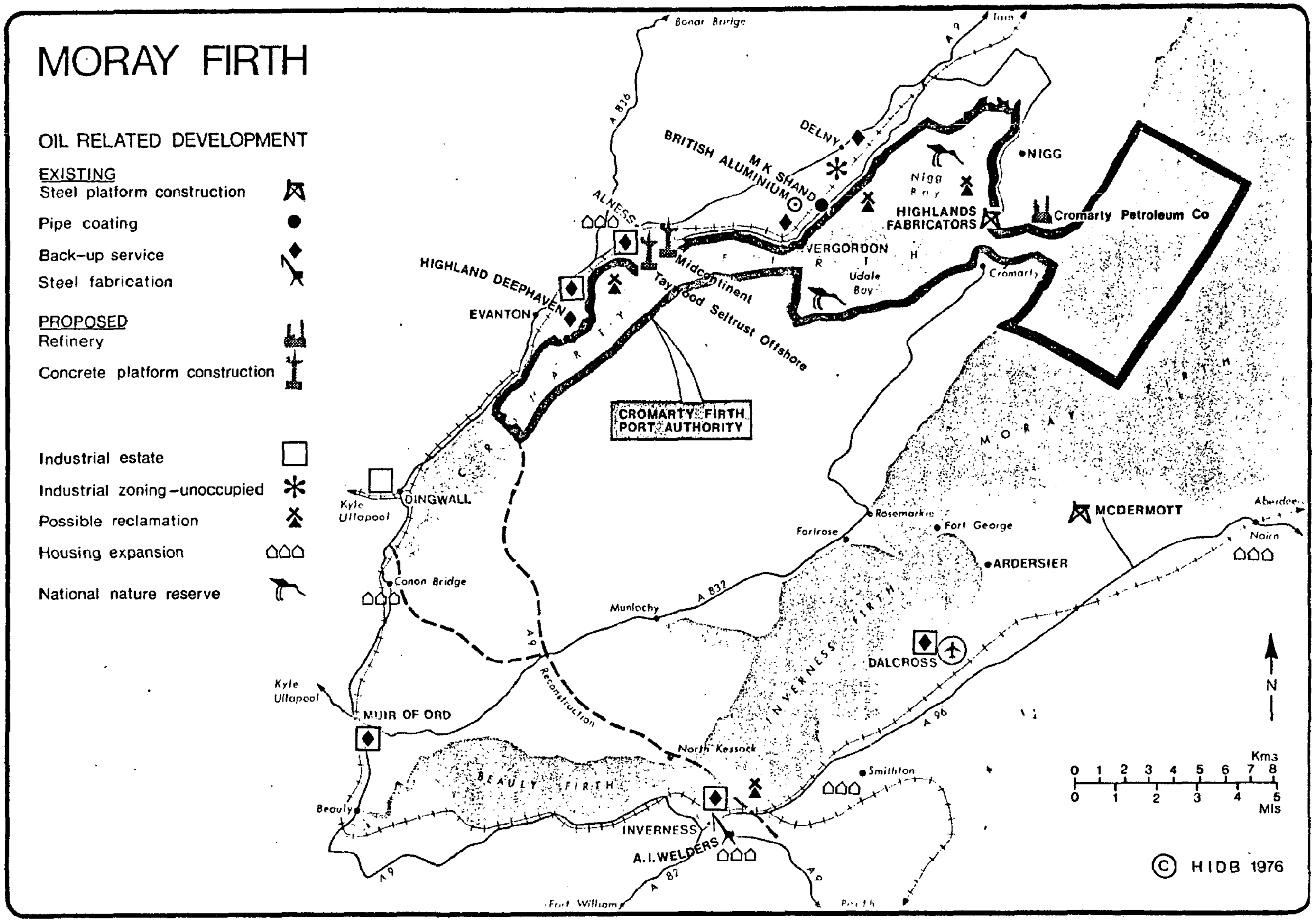
Construction camp

Helicopter base

Selected airports

OIL RELATED DEVELOPMENTS
in the Highlands and Islands




MORAY FIRTH
OIL RELATED DEVELOPMENT
EXISTING
Steel platform construction
Pipe coating
Back-up service
Steel fabrication
PROPOSED
Refinery
Concrete platform construction
Industrial estate
Industrial zoning-unoccupied
Possible reclamation
Housing expansion
National nature reserve
DELNY
BRITISH ALUMINIUM
M K SHAND
NIGG
Nigg Bay
HIGHLANDS FABRICATORS
Cromarty Petroleum Co
INVERGORDON
Udale Bay
Cromarty
ALNESS
HIGHLAND DEEPHAVEN
EVANTON
Midcontinent
Taywood Seltrust Offshore
CROMARTY FIRTH PORT AUTHORITY
DINGWALL
Kyle Ullapool
Conon Bridge
MUIR OF ORD
Beauly
BEAULY FIRTH
INVERNESS
A.I. WELDERS
North Kessock
Munlochy
A 832
A 9
Reconstruction
A 836
A 96
A 82
Fort William
Fortrose
Rosemarkie
Fort George
ARDERSIER
DALCROSS
INVERNESS FIRTH
MORAY FIRTH
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Nairn
Smithton
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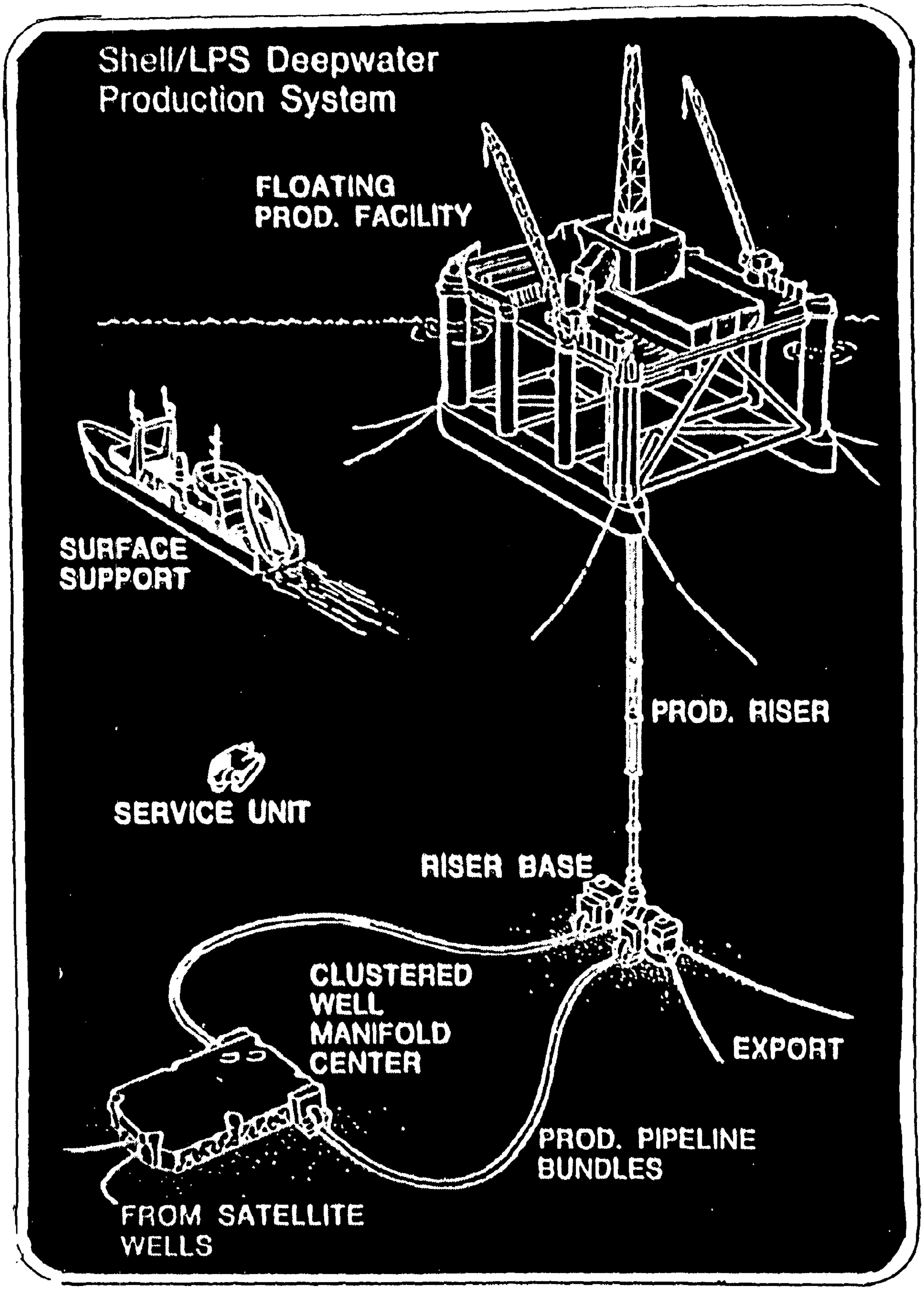
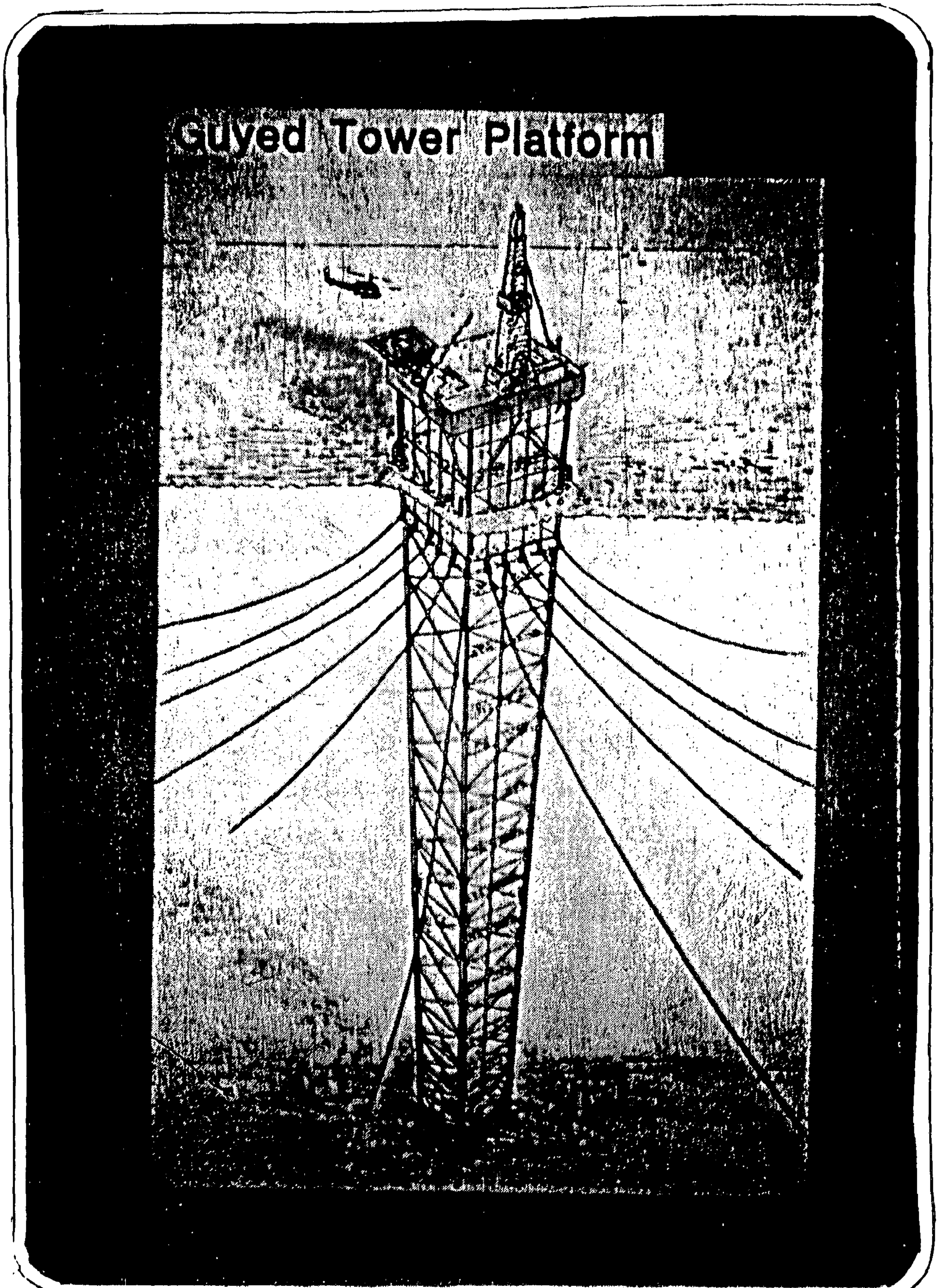
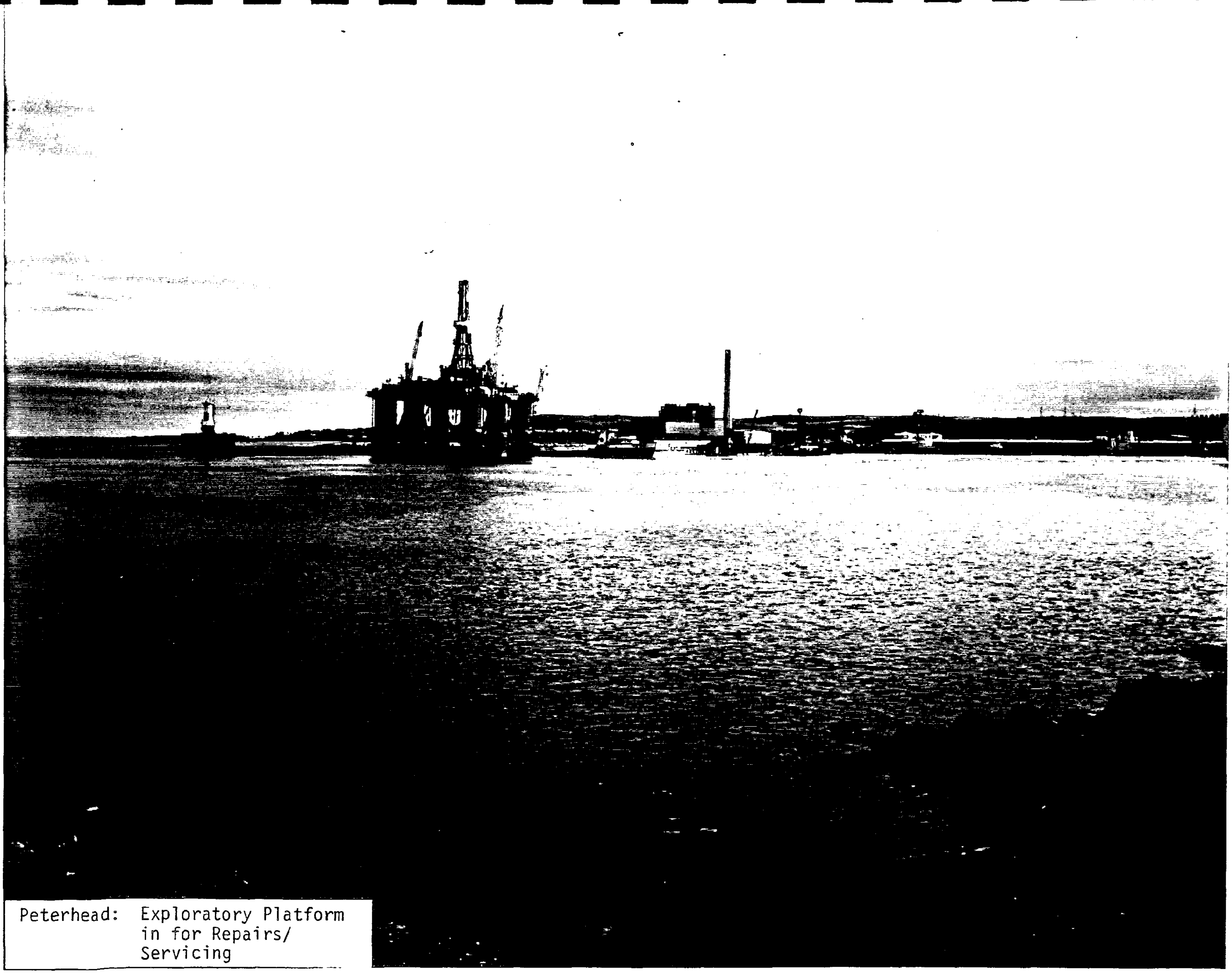
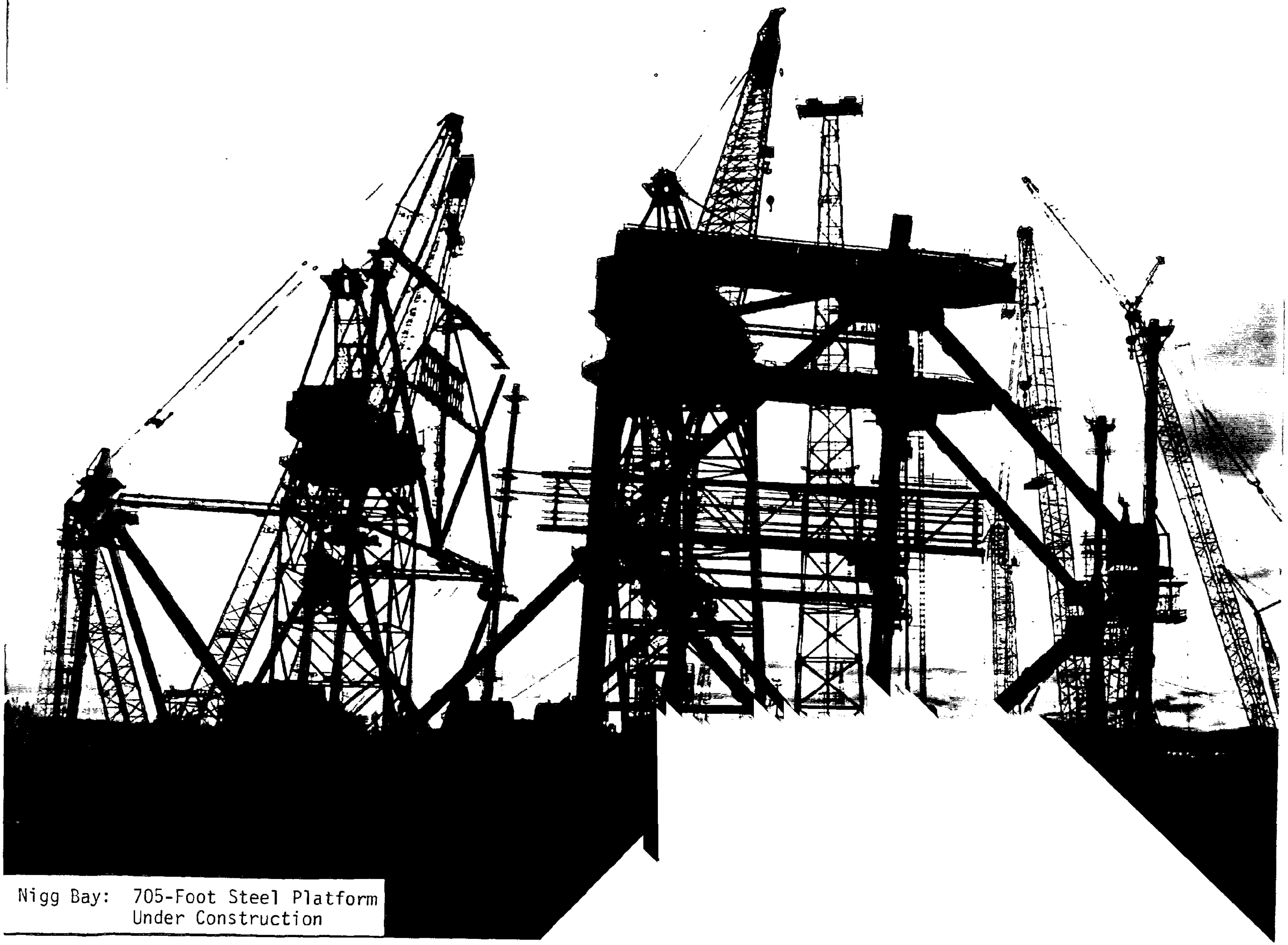

Shell/LPS Deepwater
Production System
FLOATING
PROD. FACILITY
SURFACE
SUPPORT
PROD. RISER
SERVICE UNIT
RISER BASE
CLUSTERED
WELL
MANIFOLD
CENTER
EXPORT
PROD. PIPELINE
BUNDLES
FROM SATELLITE
WELLS


Guyed Tower Platform

Nigg Bay: 705-Foot Platform Under Construction



Peterhead: Exploratory Platform in for Repairs/ Servicing



Nigg Bay: 705-Foot Steel Platform
Under Construction